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A CLIMATOLOGICAL SUMMARY OF THE SURFACE AND UPPER AIR WEATHER AT NOTS (1946–1962)

by

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ABSTRACT. This report is a 17-year summary of surface and upper-air climatological conditions experienced at the U. S. Naval Ordnance Test Station and over the Indian Wells Valley area in which the Station is located.

U.S. NAVAL ORDNANCE TEST STATION

China Lake, California

December 1962

U. S. NAVAL ORDNANCE TEST STATION

AN ACTIVITY OF THE BUREAU OF NAVAL WEAPONS

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FOREWORD

Weather conditions prevailing at the Naval Ordnance Test Station, and over the Indian Wells Valley area in which the Station is located, are summarized and discussed in this report. The summary is based upon material published by many Test Department meteorologists during the period from 1946 through 1962.

This report was written whenever operational duties would permit from March through May and during December 1962. It is released at the working level for meteorologists and others interested in NOTS weather. Work on the report was financed from Station overhead funds.

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Instrument Operations Division

Released under
the authority of
IVAR E. HIGHBERG
Head, Test Department

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This summary contains many ideas and theories previously reported by various Atmospheric Studies Branch meteorologists; it also includes data assembled from those reports. Since it is impractical to mention specific material as having come from a specific source, the author wishes to acknowledge that much of the information presented was obtained from those publications listed in the bibliography.

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INTRODUCTION

Complete weather records kept at the Naval Ordnance Test Station show the Station to have a typical desert climate--a moderate seasonal and large diurnal temperature range, low humidity, light and variable precipitation, and little cloudiness or visibility restriction. Surface winds are generally steady in direction when of significant speed. Wind speeds generally vary according to thermal conditions; the strongest gusts are usually associated with frontal passages.

Analyses of data accrued over a 17-year period, as well as the geographic and topographic background of NOTS weather origins, are given on the following pages.

A bibliography of literature covering the various fields of NOTS meteorological research more specifically, appears on page 72.

GEOGRAPHY AND TOPOGRAPHY OF INDIAN WELLS VALLEY

Indian Wells Valley lies on the northern edge of the Mojave Desert at an approximate latitude of 35°-30'N, and at an approximate longitude of 117°-30'W. The mean altitude of the valley is 2,215 feet above mean sea level. To the west and northwest are the Sierra Nevada Mountains, having westerly peaks rising above 6,000 feet, and other peaks, including Mt. Whitney, which are about 75 miles northwest and exceed 14,000 feet in altitude. The northern boundary of the valley is the Coso Range, extending above 8,000 feet. Northeast to east is the Argus Range with elevations above 6,000 feet; farther to the east are the Slate and Panamint Ranges, with peaks exceeding 11,000 feet. To the immediate south is the El Paso Range, with heights above 5,000 feet. The San Gabriel and San Bernardino Mountains, about 100 miles to the south, and the Sierras, to the west, all act as effective barriers to the moist currents of air from the Pacific Ocean.

Since the rate of evaporation exceeds the precipitation in the valley, it is classified as a desert climate and, because of the meager and erratic precipitation together with the high evaporation rate and an associated low ground-water table, there is relatively scant natural vegetation cover. During the more arid phase of the valley climate, vegetation is particularly meager and consists of many forms both unpalatable and inedible to most domestic animals. However, there is a fairly conspicuous cover of widely-spaced woody shrubs which have low grazing value. The density of the shrub cover indicates the amount of water available for plant growth. As a rule, their colors are not bright green, and during much of the year most of the shrubs look dead. The few natural succulent plants which exist in the valley resist drought by storing large supplies of water in their fleshy stems and leaves, while other perennials have developed an inherent ability to endure the drought. In some areas, short desert bunch grasses are scantily interspersed with the shrubs. They grow only in isolated bunches and, although dry for the greater part of the year, are relatively good, but meager, forage. In some places in the valley, where the soils are high in harmful alkali, a desert salt shrub vegetation consisting of rather rich green, fleshy-leafed plants capable of growing in moist saline soil, prevails. These areas have little value as grazing land.

In an inventory of the potential vegetation resources of the valley desert soil, the residual soils are of very minor importance since no matter how fertile they might be, the niggardly rainfall largely precludes their use. Gray color (with tinges of yellow, red, and brown), near-absence of humus, coarse texture, and practically unleached mineral content are the main features of the soil in Indian Wells Valley. Most characteristic is the veneer of coarse, stony, pebbly debris--the well-known desert pavement. Although desert soils are unusually high in mineral plant foods (because of a minimum of leaching), most of them are not objectionably alkaline. That condition is usually restricted to those sections where drainage waters concentrate temporarily, or where underground water runs close to the surface.

Among the several climatic realms there is no other which approaches that of the desert in the distinctiveness of its gradational landforms. The climatic stamp is more indelibly impressed upon the surface features of deserts than it is elsewhere in the world.

It is to be expected that the pattern and association of landforms in the desert will differ markedly from those developed under more humid conditions. In the latter, because of the damper earth and heavier vegetation mantle, wind action is practically nil. On the other hand, desert lands, where opposite conditions prevail, are sometimes designated the "realm of the wind". Errosion caused by the winds results in abrasion and deflation. Wind abrasion is certainly not a factor of much importance in fashioning the most striking and conspicuous landform features of the desert, although it is capable of producing peculiar

and characteristic minor features. Deflation appears to be much more important and is a major factor in lowering the floor of the desert basin.* The deflation process causes heavier materials, such as sand, to be rolled along the surface and heaped up into dunes, while the finer dust is often carried well beyond the confines of the desert.

Numerous permanent streams, occupying a most intricate and dense network of channels, are the dominant agent in most humid regions. However, there are no rivers and very few streams in Indian Wells Valley. These are sporadic in distribution, possessed of few tributaries, and are temporary in flow, but vigorous in action. Incongruous as it may seem, sporadic desert torrents are responsible for the larger and more conspicuous gradational features of the desert. The protective and anchoring effects of a complete vegetation cover are absent, so that the occasional heavy downpours result in a rapid runoff which, on the bare surface, quickly accumulates into small drainage channels. The short-lived torrents are capable of extraordinarily rapid erosion and removal, so that they can quickly scar a land surface with deeply incised drainage channels. These debris-laden streams never reach the sea; instead they deposit their loads in the form of conspicuous fans at the base of the slopes, or spread it out on the desert floor. In humid regions, permanent streams carry the rock debris to the sea, but in the desert only the winds and an occasional flash flood remove materials from the area.

Processes of erosion in the desert are highly selective in their action upon rocks. They search out the weak strata and quickly remove them, while more resistant strata stand out in harsh outline and angular profile. On slopes, the disintegrated rock is quickly removed by wind and slope wash, so that the softening effect of a deep regolith cover is absent. Moreover, the few scrubby bushes provide no effective mantle for hiding the surface forms as they are so completely hidden in tropical rainforests. The whole landscape has a stark and naked appearance, and all details of surface are boldly revealed. Because of the clarity with which earth structures are disclosed, deserts are a geologist's delight. Characteristic desert landforms vary with earth materials, structure, and stage. Indian Wells Valley has a surface composed of detached ranges of hills separated by detritus-floored basins called bolsons. V-shaped ravines and small gorges incised by occasional torrential streams stand out in sharp relief along the bare hill slopes. Spreading out from the mouth of each ravine and encroaching upon the bolson are conspicuous fans, a number of them often joining to form a piedmont alluvial belt. In the lower central part of the basin several temporary shallow lakes often form after a heavy rain, but they soon evaporate leaving behind the perfectly flat, whitish, salt-encrusted playa. It is doubtful whether any other topographical feature of the earth's surface equals the playa in flatness. It is so level that a sheet of water one foot deep could conceivably completely cover an area 5 miles in diameter.

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*For further discussion see Appendix A.

Since rivers are nonexistent, there is little water to be taken care of in the valley and the drainage pattern is relatively coarse and poorly developed. Also, since evaporation exceeds precipitation, permanent streams do not originate in (nor course through) the valley; although occasional showers may produce temporary vigorous torrents capable of rapid erosion. These intermittent native streams customarily evaporate and disappear from the desert floor, or flow into interior basins, forming playas whose dry beds are exposed most of the time. In this area, drainage tends to be interior or centripetal in character, each local depression acting as the center or focus for one or more of these transient streams.

The weathering of solid rock is a slower process in a desert climate than in a wet one, so that the residual regolith cover is likely to be thin. This is especially true in the most arid parts where vegetation cover is meager, and regolith removal by water and wind is therefore vigorous.

In this climate, runoff is relatively greater in volume and more far-reaching in its consequences than in humid regions. Pelting rains of short duration deposit water on the ground faster than it can be absorbed. As on all dry soils of fine texture, "puddling" takes place as soon as the rain begins, again retarding penetration. The sparse vegetation cover, and, in the drier portions, the presence of soil crusts and the lack of a humus layer, all tend to increase this phenomenon. The ready runoff, responsible for the short-lived torrents which fill dry-land drainage channels after a downpour, result in a two-fold loss. The much needed water is not retained by the soil, and, in addition, active soil erosion becomes a serious problem.

METEOROLOGICAL CONDITIONS AND SEASONAL EFFECTS

Great Basin High Pressure System

When an intense Great Basin High pressure system prevails, with Indian Wells Valley situated in the southern part of it, the following conditions occur:

a. With light winds aloft over the entire west coast, this synoptic situation will usually prevail from 2 to 7 days (depending on the intensity of the high pressure system).

b. Long-range forecasts can be given with the highest degree of accuracy and proficiency.

c. Indian Wells Valley will experience mostly clear skies (due to subsidence), or scattered high (cirrus) clouds.

d. In the winter, light and variable surface winds will prevail over the valley.

e. During the summer, light and variable surface winds will prevail from midnight to noon with light to fresh southeasterly surface winds occurring during the period from noon to midnight.

f. Almost invariably, the extreme minimum temperatures in winter and extreme maximum temperatures in summer occur when an intense Great Basin High prevails (and extends to high altitude), with Indian Wells Valley situated in the southern part of this high, and the winds aloft will be from the northeast to southeast direction.

Effect and Movement of Frontal Systems

Frontal systems in the Indian Wells Valley area can be typed into two general classifications: slow and fast moving.

Winds aloft during slow-moving frontal systems are nearly parallel to the frontal system, or form a closed low aloft over California. Such synoptic conditions will influence the weather in this area for a period of from 2 to 6 days. This particular type of synoptic situation will produce low ceilings, thunderstorms, lightning, rain, snow, or hail, depending on air temperature, total moisture content, and the intensity of the horizontal convergence-lifting involved.

During the presence of fast-moving frontal systems, the winds aloft are nearly perpendicular to the system. A "rule of thumb" is that the system will pass the valley 24 hours after it passes San Francisco. This type of synoptic situation will produce strong and extremely gusty surface winds before, during, and after the surface frontal passage over the valley. There will be low moisture content, very slight horizontal convergence, and no phenomena such as thunderstorms, rain, snow, hail, or cloud ceilings.

It is difficult to determine whether these fronts will break through the mountains from the north or from the west quadrant. Warm moist air appears to flow in aloft from the south or southwest in connection with a low pressure center over northern Utah or central Nevada. When this occurs it is quite likely the valley will experience frontal weather before the true frontal passage has occurred. There is a marked lag of approximately 2 to 3 hours in frontal passages, due to the presence of the high Sierra Mountain range to the west and north. Fronts affecting this area most generally enter California at the California-Oregon boundary, or in the vicinity of Salinas, California, and southward.

THE THREE WEATHER SEASONS OF INDIAN WELLS VALLEY

There are three main weather seasons in the valley:

1. The windy months with occasional frontal passages (February through April).
2. The warm months when the thermal low predominates, and there are moderate to fresh afternoon surface winds (May through September).
3. The months when surface winds are generally light and variable throughout the day (October through January).

Seasonal Effects

Spring and Fall. These seasons fall between the periods during which frontal systems almost always pass this area and when frontal systems infrequently pass this valley.

Winter. In the winter, this region is usually covered by a moderately strong anticyclonic condition, except during periods of frontal activity. The Pacific High has retreated southward so that cyclones can now enter the California coast. An average of 20 to 30 frontal systems pass the valley during winter months. However, most of these systems are fairly weak by the time they cross the local area.

The mountain-valley breeze exists to some extent in winter, but because the winds are lighter than in summer, their directions are more variable. Frontal passages during the winter produce surface winds usually 25 to 35 miles per hour and, at times, greater than 45 miles per hour. However, these extreme winds are usually of short duration. Strong northerly surface winds occasionally occur when the circulation from an intense high in the Great Basin spills southward along the east slopes of the Sierra Nevada. These strong winds may be expected when a strong pressure gradient is established by the Pacific High Cell pushing onshore and displacing a low centered over southern Nevada.

During the winter months when moist, unstable maritime air is forced against the mountains to the south, southwest, and west, a continuous line of towering cumulus clouds is formed. Occasionally a warm front will approach the southern California coast from the southwest, or perhaps as a wave on a southeastward moving cold front. If a closed low exists aloft at about 10,000 feet, the surface low may remain over central and southern California for several days. The resulting circulation will produce ceilings near 5,000 to 6,000 feet, with accompanying precipitation usually light and intermittent; but well-developed cold lows aloft occasionally produce precipitation of greater intensity and longer duration. The snowstorm during 11-14 January 1949 is an example of such a situation (see the section on precipitation on page 17).

The first front usually occurs about the middle of October and the average length of the front period is 5 to 6 months. As this valley is in a region of uneven surface configuration, the cold stratum of air next to the earth's surface, because of its greater density, slips off the surrounding mountain ranges and flows down into the valley. This phenomenon is known as air drainage. On clear cold nights when air drainage and temperature inversions are prevalent, there will be considerable frost in the valley.

This season encompasses a large percentage of days during which surface winds will record light and variable for the complete 24-hour period.

Summer. During the summer the Pacific High is well-developed to the west of California, and a thermal trough overlies the Valley. The intensity and position of the thermal trough varies from day to day and its depth is about 5,000 to 6,000 feet. Although the rugged mountainous country prevents a normal circulation, southerly winds are predominant. The weak Pacific occlusions that enter the country come from well up on the Canadian coast. There are no fronts of consequence, and Polar outbreaks are unknown. Continental Tropical Air predominates, resulting in hot days and warm nights. Maximum temperatures average highest in July and August, and high diurnal variations occur during the summer.

During the winter, thermal winds are not a frequent occurrence, but as summer approaches they become more and more common. The important weather phenomena to be noted are occasional strong gusty winds (see the section on surface wind on page 9) produced by afternoon convection from intense surface heating. These winds cause dust storms (page 15) and dust devils (page 32) of varied dimensions, with consequent low visibilities.

If the orientation of the thermal trough is northeast-southwest such that Maritime Tropical Air is brought into the area, thunderstorms are likely to develop in the afternoon over the mountains west and northwest of the valley, dissipating in the evening. Severe turbulence and restricted visibility due to rain are then encountered. Thunderstorms are not common over Indian Wells Valley during the spring, summer, and fall. During a four-year period only 15 thunderstorms (not necessarily accompanied by precipitation) were reported. Occasionally in the summer the air is unstable, and cumulus and cumulonimbus clouds build up on the Sierra Nevada; sometimes altocumulus and cirrocumulus clouds may be developed and blow over towards the valley. Precipitation is rarely produced in the valley from this activity, but does occur occasionally over the mountains. Visibility is generally unlimited throughout the summer months, except during local dust storms.

During this season there is a very high percentage of days during which the surface winds will record light and variable during the after-

noon and evening. A very low percentage of the fronts that come inland on the west coast will pass the valley and influence the weather in this area.

GENERAL YEAR-AROUND WEATHER CONDITIONS

The meteorological properties of the valley can best be described in the following general terms which constitute a very broad and year-around summation:

a. It has a desert climate with moderate extremes in temperature.

b. Relative humidity is very low.

c. Light winds prevail during the night and early morning hours and frequent moderate-to-strong winds occur during the afternoons. Winds of gale force occur occasionally during periods of strong frontal activity.

d. There is a very high incidence of clear skies with accompanying good visibility.

e. Winds are generally steady in direction when of significant velocity. Velocities usually vary according to thermal conditions; the strongest gusts are ordinarily associated with frontal passages.

ADVERSE WEATHER INDICATORS

Indicators of adverse weather conditions over Indian Wells Valley are summarized below:

a. The formation of lenticular clouds to the west or directly over the valley indicates strong surface winds (see section on mountain waves, page 38).

b. Stratus-type clouds hanging over the mountains to the west of the valley with moderate upper winds from a westerly direction indicate an excellent probability of strong surface winds in the valley during the day; if the upper winds have an easterly direction, the probability is for light surface winds.

c. If Owens Valley (to the north) or Indian Wells Valley has had a recent light rain shower, it will take surface winds of 35 to 40 knots, instead of the usual 25 knots, to cause the sand or haze to move over the Indian Wells Valley.

d. The maximum diurnal pressure change in the valley occurs at approximately 1100 PST and the minimum at approximately 1700 PST. If the pressure falls at 1-1/2 millibars per hour or less during that time, it is a good indication that normal weather conditions will prevail. If the pressure falls faster than 1-1/2 millibars per hour, it is an excellent indicator for moderate-to-strong surface winds within the next hour.

SPECIFIC WEATHER PHENOMENA

Surface Wind

Dry regions are inclined to be windy since little friction is generated between the moving air and the low, sparse vegetation cover. In this respect they are like oceans. Moreover, the rapid daytime heating of the lower air over the desert leads to convectional overturning. This interchange of lower and upper air tends to accelerate horizontal surface currents during warm hours when convection is at a maximum. Because of the strong and persistent winds, the air is often murky with fine dust. There tends to be much less wind activity at night, which is a partial explanation of the rapid nocturnal cooling of surface air.

Wind directions are predominantly from the southwest or west-southwest with a tendency toward the more westerly direction during the winter months. Two main factors are responsible for this local circulation: In the first place, the valley is surrounded by mountains, and airflow into the valley, at low levels, is through four main passes in these mountains. The prevailing flow is through Walker Pass and Tehachapi Pass, to the southwest; air from the north must come through Little Lake Gap, to the north-northwest; and the other pass is southeast, separating the Argus and El Paso Mountains. Secondly, the thermal low predominates over this area from May to November, which means that the local pressure gradient is almost always easterly throughout those months. However, when a Basin High pressure system exists, or when a large high moves out of Canada and south along the Rockies, the local winds obtain an easterly component which may persist for several days, dependent upon the intensity of the high pressure cell. After heating takes place and convection sets in, the surface winds generally follow the same lines of flow as those at the gradient level. It should be noted that a westerly flow aloft tends to become southwest at the surface, while easterly winds aloft show very little change at the surface.

The advent of westerly winds in the Valley may be likened to water spilling over a dam, wherein Bernoulli's Principle applies. As the stream of water, or of air, moving along with a certain velocity is confronted by a barrier, such as a mountain range or a river dam, one of two things must happen: the flow across the boundary either ceases entirely or the fluid is forced to flow with greater velocity over the

top of, or through an aperture in the obstruction. Considering the atmosphere alone, and by applying Bernoulli's theory, we find that the velocity with which the air is moving will increase proportionately as the diameter of the aperture through which it flows is decreased--an inverse relationship. Thus, a mass of air crossing over the top of a mountain range (e.g., the Sierra Nevada), is squeezed between the air mass above and the mountain range beneath and the velocity of the air particles is therefore increased.* As the air passes to the lee side of the mountain range, the turbulent leeside eddy is formed. Then the surface winds on the leeside become extremely gusty, with strong turbulence aloft. Winds of this nature do not appear sufficiently strong enough to prevent the surface temperature inversion (page 29) from forming during the hours after sunset. The radiation inversion, in turn, presents a barrier of stable air to the 30 to 35 mile-per-hour gradient winds and prevents them from reaching the surface. The surface winds pick up after 0930 PST as the inversion is destroyed by daytime heating.

It is quite evident that the highest velocities are reached during the late winter and spring months, with the maximum hours of winds exceeding 30 mph coming in February, March, April, May, and June. During the summer months the tendency is toward fewer hours of excessive winds but more hours of moderate velocity (20 to 30 mph). It can safely be said that during this period the maximum wind speed for the day will exceed 20 mph on 20 to 30 days out of the month. This maximum occurs late in the afternoon between the hours of 1500 and 1900 PST and is frequently of a gusty nature. In addition, a tight pressure gradient and strong surface winds occur in the valley when the Pacific High Cell pushes onshore and displaces a low centered over southern Nevada. These winds are westerly in direction. Strong surface winds at night are rare but do occur with frontal passages, thunderstorms, or with the presence of a deep low pressure system in the immediate vicinity. Generally, winds with an easterly component in the valley bring increasing temperatures, and westerly winds bring lower temperatures. When certain pressure conditions exist, strong winds from the southwest and northerly directions occur. When the air flow aloft is strong west or northerly, the winds on the lee side of the mountains may be very erratic, which may necessitate suspension of flying activity. With a cold front or cold-front type occlusion moving in from the Pacific Ocean, the surface wind in the valley will usually exceed 20 mph from the southwest for from 6 to 12 hours before the front reaches the valley. After the frontal passage, winds will be west to west-northwest and may reach speeds of 35 to 50 mph. This is especially true when a wave forms on the front in the Las Vegas/Salt Lake area, as the low pressure intensifies circulation in this valley.

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*The quantitative discussion of airflow over mountain ranges is complicated. It is known that waves form to the lee of the Sierra Nevada Mountains and that their structure apparently depends upon the velocity of air flow, the stability of the air, width and shape of the mountains, and probably other factors. See p. 38.

Because of the topography of the valley (nearly level throughout the floor but surrounded by relatively high mountains), the surface winds do not necessarily follow the winds aloft pattern as might be expected, but many times are forced around the mountains and accelerated through the passes. Consequently, winds entering the valley through the passes have jet-like characteristics which may give strong or gale force winds to one sector of the valley and light and variable winds to other sectors. Thus with a moderate westerly wind aloft over the valley, we may have strong southwest surface winds over other sectors. At other times, strong northwest winds aloft over the valley may never reach the surface; or if they do enter the valley, they may affect only the western side of the valley.

The following factors pertain to strong westerly winds:

a. Strong westerly winds are more frequent in March.

b. Gusts of over 40 knots are unlikely without frontal activity.

c. Strong gusts are infrequent during the winter and spring seasons with fronts traveling less than 20 mph; the frontal speed is usually 25 mph or more.

d. Strong winds can be expected after the front reaches Fresno. The area of southern Nevada and Arizona should be watched closely after the front has passed this valley, for indications of possible post-frontal winds.

e. The peak gust is usually southwest through west, 40 to 45 knots.

f. If the wind at 10,000 feet is over 35 knots, the peak gust is likely to be over 45 knots.

g. With a pressure gradient of 10.0 to 12.5 millibars from Bakersfield to Las Vegas, the peak gust is likely to be over 45 knots, and is almost certain to be so if the gradient is more than 12.5 millibars.

Surface winds averaging 15 mph or more during this 17-year period are charted in Table 1, and peak gusts of over 40 mph are charted in Table 2.

Strong northerly winds (which do not occur frequently in the valley) of only 30 knots may cause a rapid decrease in visibility, especially over the northern and western parts of the valley. This sharp visibility decrease is apparently the result of alkali dust, from Owens Valley and beyond, blowing through the mountain gaps northwest and north of the valley. The year-to-year occurrence of these winds has been erratic, coming mostly in the months of November through March, given the following conditions:

a. A surface (m.s.l.) pressure of 1,025 to 1,030 millibars, usually centered in northern California, Oregon, or Washington.

b. A northwest through north wind at 10,000 feet 12 hours in advance, becoming predominately north.

c. The actual or probable occurrence of a trough or low center at 10,000 feet in Arizona or southern Nevada.

d. A temperature of -10°C at 10,000 feet at Las Vegas.

e. A north-to-south surface pressure gradient of 10 millibars between Reno and Burbank.

TABLE 1. Number of Days* in Which Surface Winds Averaged 15 mph or More

	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	Total	Av.
Jan	1	6	5	4	5	5	6	3	5	3	1	0	0	0	2	46	3.1
Feb	3	6	2	8	2	5	5	5	4	3	3	3	3	0	7	64	4.3
Mar	6	10	7	4	11	11	11	5	5	7	8	3	6	9	6	109	7.3
Apr	15	4	7	6	3	10	7	16	8	8	5	4	7	6	3	109	7.3
May	3	10	6	8	3	11	6	10	8	8	1	5	3	8	9	104	6.9
Jun	2	6	7	1	8	6	7	7	4	10	5	3	1	0	3	70	4.7
Jul	4	4	2	4	1	2	4	3	4	9	0	1	2	1	2	43	2.9
Aug	4	2	6	3	2	9	9	0	2	3	0	2	3	0	4	49	3.3
Sep	1	4	2	0	3	0	3	6	2	1	3	3	1	2	0	31	2.1
Oct	1	6	9	3	0	4	1	4	6	2	3	2	3	6	6	56	3.7
Nov	2	3	6	4	2	3	2	7	1	3	3	0	1	0	1	38	2.5
Dec	3	5	4	9	3	3	2	8	3	2	0	3	3	0	0	48	3.2
Year	55	66	63	54	43	69	63	74	52	59	32	29	33	32	43	769	51.3
Aver.	4.6	5.5	5.2	4.5	3.6	5.8	5.2	6.2	4.3	4.9	2.7	2.4	2.8	2.7	3.6		4.3

*24-hour periods

TABLE 2. Number of Days* in Which Peak Gusts of Wind Exceeded 40 Miles per Hour

	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	Total	Av.
Jan	2	9	7	1	4	5	4	3	6	5	1	2	0	0	2	51	3.4
Feb	6	6	1	1	7	9	2	5	6	4	4	1	7	0	3	62	4.1
Mar	8	12	10	4	8	7	8	7	6	9	3	4	3	9	6	104	6.9
Apr	17	2	7	6	5	12	4	14	7	11	5	2	1	3	4	100	6.7
May	8	8	7	10	4	6	5	8	8	3	1	5	3	4	6	86	5.7
Jun	7	4	6	1	6	4	5	3	3	5	3	2	2	0	3	54	3.6
Jul	5	2	2	2	1	1	4	3	2	1	0	0	3	0	1	27	1.8
Aug	3	2	8	1	0	4	1	0	1	**	0	0	1	1	2	24	1.6
Sep	4	2	2	0	2	0	3	5	0	**	2	0	0	0	1	21	1.4
Oct	0	6	3	3	0	1	1	3	4	**	1	2	0	5	2	31	2.1
Nov	6	3	4	3	3	2	3	7	2	**	1	0	2	0	0	36	2.4
Dec	4	4	1	8	1	3	2	7	2	1	0	2	0	1	0	36	2.4
Year	70	60	58	40	41	54	42	65	47	39	21	20	22	23	30	632	42.1

*24-hour periods

**Data missing

Dust and Sand Storms

The dust storms which occasionally occur in the valley consist of dust and sand raised by the wind to such an extent that the horizontal visibility is considerably diminished. The dust and sand are rarely carried very far from the source. The conditions favorable for the formation of dust storms and sandstorms are: extreme dryness of the ground, unstable and turbulent air, steep lapse rate of temperature, and high wind velocity, Appendix A. Local sand-blowing in the valley is caused by a surface wind with a southerly component accompanied by a velocity in excess of 25 to 30 mph. Such winds accompany the passage of depression. It has been observed that violent dust storms and sand storms have resulted from strong southwest and west winds within 4 or 6 hours before and after the passage of a cold front. Sand storms have occurred, though infrequently, at night and in almost every case the storm has been associated with the movement of a depression through this area. When a moderate to severe dust storm occurs, visibilities are reduced to as low as 1/2 to 1-1/2 miles and last 1 to 2 hours. Pilots have reported the tops of the dust layer at times to be 4,000 to 6,000 feet above the valley. In addition to the dust storms that occur with frontal passages, winter dust storms are also generated by winds from off the mountains. These northerly winds are produced by a strong pressure gradient occasioned by the stagnation and intensification of the Great Basin High pressure system.

Possible indications of windstorms, accompanied by strong gusts and blowing sand are:

a. Deepening low pressure in this area and to the east associated with rising pressures to the west and northwest. This increasing pressure gradient will be evident in the 5,000- and 10,000-foot winds in advance of the increasing surface winds.

b. A frontal system through the northwestern states with the low pressure trough extending through this area.

c. Advection of cold air with northwesterly winds and increasing relative humidity as indicated on the 10,000-foot weather chart, and particularly at levels of 7,000 to 14,000 feet over this valley while the surface winds are still from the southwest.

d. Above-normal temperatures and dewpoints at the surface associated with the other phenomena listed above.

Cloudiness

Ceilings over the valley usually are above 6,000 feet, except during a few occurrences when the ceiling will drop to as low as 1,000 to 3,000 feet during the passage of a warm-type occluded front, or during periods when intense cold low pressure systems aloft persist over the area. Much

of the cloudiness is of the high thin type, which does not seriously affect lighting. Sunshine over the valley is estimated to be present 80 to 90% of the daylight hours during the year. Table 3 is a comparison of the relative amounts of solar radiation received at Los Angeles and at Indian Wells Valley. Note that this valley receives over 25% more insolation than does Los Angeles. Table 3 presents the average daily values of insolation (direct and diffuse) received on a horizontal surface and is tabulated in langleys, the unit used to denote one gram calorie per square centimeter.

TABLE 3. Three-Year Tabulation of Solar Radiation at NOTS and Los Angeles

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av.
1953	NOTS	305	410	557	663	766	828	754	727	640	500	358	310	568
	LA	248	380	472	487	637	596	653	587	484	392	284	261	457
1954	NOTS	303	439	606	792	799	847	803	714	651	510	385	274	588
	LA	250	359	462	562	498	537	622	601	493	332	276	186	432
1955	NOTS	293	397	591	760	782	851	836	776	669	458	372	302	591
	LA	215	255	445	518	597	592	660	605	504	344	277	243	438

Annual Means: NOTS--582, Los Angeles--442

Surface Relative Humidity

The relative humidity in summer is very low, averaging 30 to 50% in the early morning hours and 10 to 20% during the late afternoon, with humidities below 10% not uncommon during the hottest part of the day. The year-round average relative humidity is 36%. These conditions promote intense heating during the day in summer and marked cooling at night. Relative humidity averages are given in Table 4.

Upper-air relative humidity data is intentionally omitted from this report for several reasons. First, the arbitrary hours at which the upper-air soundings are taken at NOTS tend to present a confused picture of the actual mean relative humidity conditions aloft. That is, if most of the soundings are taken in the early morning hours over a given period of time, the humidity will apparently be unseasonably high whereas if the soundings are taken in the afternoon the humidity will appear to be unseasonably low during the period, particularly during the summer months. Second, the sensing element used to measure the humidities aloft will not respond to values of humidities of less than 15%. Therefore, if the sound-

ings indicating a lesser humidity are ignored there is a tendency for the remaining humidities to appear unseasonably high. Third, the sensing element will not respond accurately to humidity values when the temperature is below -40°C. This factor alone would, in any event, tend to limit such information to altitudes below about 31,000 feet.

Because of the absence of accurate humidity data, the densities computed for Appendix B were obtained by assuming 0% humidity at all levels.

TABLE 4. Relative Humidity Averages, 1946-1962

	Percent of Saturation		
Period	Average of Daily Minima	Average of Daily Maxima	Average Humidity
January	34	74	53
February	26	71	46
March	21	62	39
April	17	54	34
May	15	48	30
June	12	39	24
July	13	37	23
August	13	40	25
September	14	44	26
October	18	50	32
November	24	65	43
December	32	76	53
Year	20	55	36

Precipitation

Indian Wells Valley is located about 150 miles inland from the Pacific Ocean in the center of surrounding highlands that block the entrance of humid maritime air masses. Thus, free entrance of rain-bearing winds is greatly impeded.

Rainfall, always meager in the valley, is also extremely variable from year to year so that the average is not dependable. As a general rule, dependability of precipitation probability figures usually decreases as the amount of precipitation decreases. Table 5 lists the annual amount of precipitation in this area; Table 6 tabulates the number of days in which more than a trace of precipitation occurred.

Usually only light showers fall, even in winter, except from deep slow-moving warm front type occlusions or cold low pressure systems aloft.

These occlusions, especially those forming between Honolulu and southern California, may bring copious rain, often 1 to 2 inches in a few days.

Snowfall is rare (only 15 days of snowfall were recorded during a 13-year period). However, during the period 11 to 14 January 1949, snow, reaching depths of from 12-14 inches, fell over the southern portion of the valley. This storm occurred during a period of low zonal index, when a cold low pressure system aloft dominated the area.

The following conditions usually prevail at times of 'trace' precipitation (precipitation observed but in an amount less than 0.005 inch):

a. Frontal activity is the cause of trace precipitation about half the time.

b. Frontal speed is less than it is when high westerly winds result, the median speed being about 20 mps as compared to 25 mph.

c. Wind speed at 10,000 feet is less than it is when high westerly winds occur, the median speed being 30-35 knots as compared to 35-40 knots.

Measurable precipitation usually occurs under the following circumstances:

a. When there is frontal activity and generally cold or occluded fronts, but occasionally with slow-moving or stationary ones.

b. When frontal speed is 20 mph or less; seldom with fronts moving 25 mph.

c. When wind at 10,000 feet reaches 30 to 35 knots southwest 12 hours before and at the time of precipitation.

Precipitation usually begins after the front reaches the Fresno area.

The following patterns generally exist under summer shower conditions:

a. Summer showers are most frequent in July.

b. The wind-flow at 10,000 feet is usually east to southeast at 10 to 20 knots locally, and easterly over southwestern U. S.

c. Measurable precipitation and thunderstorm activity are possible but unlikely.

d. There is a possibility of gusty easterly surface winds, 35 to 45 knots.

TABLE 5. Precipitation, Measured in Inches

	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	Av.
Jan	T*	T	T	0.55	0.09	0.08	2.13	T	1.41	0.48	0.71	1.00	0.38	0.50	0.47	0.35	0.54	0.51
Feb	0.07	0.04	0.19	0.14	0.16	0.01	0.15	0	0.40	T	T	0.41	1.53	0.84	0.91	T	0.62	0.32
Mar	0.24	0.08	0.02	0.14	0.05	T	1.76	T	0.45	0	0	0.02	0.65	0	T	T	0.09	0.21
Apr	T	0.44	0.06	0.05	T	0.01	0.05	0.06	0	0.01	0.94	0.01	0.58	T	0.04	T	0	0.13
May	0	T	0.16	0.03	0	0.13	0	T	0.02	T	0.01	0.06	T	0.03	0	0	T	0.03
Jun	0	0	0.10	T	T	0	T	0	0	0	0	0.03	0	0	0.29	0	0	0.02
Jul	0.03	0	0	T	0.18	T	0.02	0.02	0.05	0	T	T	T	0	0.05	0	T	0.02
Aug	T	T	0	0.03	T	T	T	T	T	0	0	0	0.01	T	0	0.55	T	0.03
Sep	0.02	0	0	T	0.78	0	0.12	T	0.41	0	0	0.05	0.15	0.70	0.29	T	T	0.15
Oct	0.17	0.42	T	T	T	T	0	T	0	0	0.07	0.03	0.40	T	T	0.11	T	0.07
Nov	1.87	T	0	0.04	0.02	0.05	0.55	0.06	0.76	0.05	0	0.16	T	0.14	0.93	0.99	T	0.33
Dec	1.09	1.05	0.34	0.32	T	0.56	1.10	0	0.57	0.02	0	0.91	0	0.77	0.03	0.46	T	0.42
Year	3.49	2.03	0.87	1.30	1.28	0.84	5.88	0.14	4.07	0.56	1.73	2.68	3.70	2.98	3.01	2.46	1.25	2.24

Number of Days With Snow

Jan				Feb		Mar		Dec		Year			
1948	1	1955	3	1946	1	1951	1	1948**	1	1946	1	1955	3
1949	7	1957	2	1949	1	1952**	2	1951	1	1948**	2	1957	2
1951	1	1960	2	1962	2			1960	1	1949	8	1960	3
1954	1	1962	2					1961	1	1951	3	1961	1
										1952**	2	1962	4
										1954	1		

*T (Trace)--precipitation less than 0.005 inch

**Days with snow and rain mixed

TABLE 6. Number of Days in Which 0.01 Inches or More Precipitation Occurred

	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	Total
Jan	0	0	0	4	1	2	9	0	3	3	2	3	4	1	3	1	2	38
Feb	2	1	1	1	3	1	1	0	2	0	0	2	4	4	5	0	5	32
Mar	3	1	1	1	1	0	4	0	2	0	0	1	3	0	0	0	2	19
Apr	0	2	1	1	0	1	2	2	0	1	2	1	4	0	1	0	0	18
May	0	0	1	1	0	2	0	0	1	0	1	2	0	1	0	0	0	9
Jun	0	0	2	0	0	0	0	0	0	0	0	1	0	0	1	0	0	4
Jul	1	0	0	0	1	0	1	1	1	0	0	0	0	0	1	0	0	6
Aug	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	4	0	6
Sep	1	0	0	0	3	0	2	0	1	0	0	1	2	3	2	0	0	15
Oct	2	2	0	0	0	0	0	0	0	0	1	2	1	0	0	1	0	9
Nov	3	0	0	1	1	2	2	1	1	2	0	1	0	2	3	2	0	21
Dec	5	2	2	1	0	4	5	0	2	1	0	4	0	3	1	1	0	31
Year	17	8	8	11	10	12	26	4	13	7	6	18	19	14	17	9	9	208

Thunderstorms

Thunderstorms are not common directly over the valley and do not usually constitute a problem in the valley area. Heavy and swelling cumulus clouds are noted frequently over the mountains, but seldom reach the thunderstorm stage. Thunderstorms occurring most frequently have been of the air mass type, rather than the cold front type. The main factors that contribute to the formation of the storms, in addition to the necessary instability of the air mass, are: a well-developed thermal trough of low pressure over the interior of California, a diurnal heating, and a flow of moist air over this region.

Despite the vigorous diurnal convectional currents, normally the whole mass of air is too warm and has too low a relative humidity to allow these rising air currents to exceed the condensation level and produce thunderstorms. Dark cumulonimbus clouds, sometimes accompanied by thunder and lightning, do form occasionally over the mountains to the northwest, but the streamers of rain that can be seen descending from them (called virga) usually evaporate in the arid atmosphere before they reach the earth. Even though the air itself may be dry and have unusual evaporative power (high temperature and low relative humidity), there is usually a moderate amount of moisture in the atmosphere. What is lacking is a way to cause it to be condensed and precipitated.

Temperatures

The mean distribution of solar energy is such that, of the total amount received at the outer limits of the atmosphere, approximately 42% is reflected back into outer space either from the tops of clouds or by the diffuse atmospheric reflection phenomenon called scattering. Another 15% is absorbed by the gases and water vapor present in the atmosphere, and the remaining 43% is absorbed by the earth's surface. Reflection to outer space varies with the amount of cloudiness present in a given region. Atmospheric absorption varies with the amount of water vapor present, and terrestrial absorption varies with the albedo or reflectivity of the particular surface. A sand surface has a relatively high albedo; dark earth surfaces tend to act more like black bodies in absorptive power. Water surfaces vary in absorptive power with the angle at which the sun's rays strike the water, being high when the sun is overhead and low when the sun strikes the surface at an acute angle, since much of the energy is then reflected.

However, in a study of solar heating in a particular region, most of the above variables must be disregarded. In Indian Wells Valley we are particularly fortunate in having an exceptionally constant atmosphere. Moisture content is generally low, heavy cloudiness is relatively rare, and the amount of insolation is mainly dependent on latitude and seasonal characteristics.

The measurement of the temperature of the lower layers of the atmosphere near the surface of the earth is important in the study of small-scale meteorological effects and for a better understanding of the climate of the layer of air in which most animals and plants exist in this desert. The measurement of soil surface and subsoil temperatures is important in the study of the transport of heat to and from the earth in the maintenance of the heat balance of the atmosphere.

These temperature measurements are of interest locally to those who design and construct facilities on, near, or under the earth's surface. The design and construction of these installations are often critically dependent upon the surrounding temperatures. Although considerable climatological measurements data have been published, the greater part has been put out for agricultural uses. Few measurements of this type have been made in dry, hot, desert regions similar to that surrounding Indian Wells Valley.

The seasonal changes in the average lapse rate of air temperature in the lower levels (below 10 feet) indicate that there is a definite decrease in lapse rate from summer to winter during the morning hours. During the afternoon hours there is even a more definite decrease in the lapse rate from summer to winter. This corresponds to the decrease in radiation received at the earth's surface and transferred to the air as heat during these periods.

For every month, both morning and afternoon, the average lapse rate of temperature is greater than the adiabatic. It is very much greater during the afternoon hours, particularly during the summer months. For July the average lapse rate from 2 inches to 10 feet is as much as 250 times the adiabatic lapse rate.

A comparison of temperatures under coverings of natural sand, macadam, and concrete has indicated that there is no significant difference of the mean temperatures under the various covers. The temperatures under sand and concrete covers at the 6-inch and 12-foot levels will be nearly the same while those under the macadam at those levels, will be consistently 2 to 5°F higher.

The seasonal trend of the mean temperatures at levels below the earth's surface shows a significant change of the lapse rate from one of increasing temperature with depth to one of decreasing temperature with depth being very evident during March and April. The inverse change in sign of the lapse rate occurs in September and October. With depth, decreasing amplitude of the temperature versus height is evident as well as a lag in conduction of heat downward. The maximum mean temperature at the -10-foot level occurs in August, or two months after the maximum mean temperature occurs at the -6-inch level.

There is a considerable difference in the range of the means and extremes of the afternoon soil surface temperatures as compared with the

mean maximum air temperature at the 5-foot level. Since the layers of air near the soil surface closely approach the temperature of the soil surface, the difference between these two temperatures represents the mean temperature lapse rate of the air between the soil surface and the 5-foot level. The lapse rate for July is 34°F from approximately 1 foot to 10 feet. Obviously then, the large change in temperature lapse rate occurs below the 1-foot level, and more exactly, below the 2-inch level. When considering the general characteristics of the conduction of heat through the soil, it will be found that subsoil temperatures will show the effect of heat being conducted through the soil in the manner of a dampened sine wave propagated downward and completely damped below the 10-foot level.

A comparison of the short-range temperature changes below the soil surface will make quite evident the difference between the amplitude changes in the lag in conduction downward. Even at the -1-inch level, the maximum temperature occurs 5 hours after the air at the 5-foot level has reached a maximum temperature.

The damped sine wave nature of the conduction of heat through the soil during a 24- to 48-hour period is evidenced by the fact that during these short term periods, the temperature, which varies from 5°F to 11°F at the -1-inch level, becomes essentially constant below the -1-foot level. The change in temperature below this level will be appreciable only over long periods. That there is a change in temperature below the -1-foot level is indicated by a yearly variation of 15°F in the mean temperature at the -10-foot level. It can be said, then, that there will be little variation of temperature below the -10-foot level, even with a large variation in the surface and air temperatures.

Generally, the summers in Indian Wells Valley are inclined to be very warm to hot, while winters are correspondingly cold. As a result of the prevailing dryness of the ground, the arrival of spring is relatively sudden, so that the warm season advances rapidly. The quick rise in spring temperatures is much greater than in more humid climates, where a large part of the sun's energy is expended in melting snow and evaporating the water, rather than in heating the ground and air.

Due to its interior location, the valley has relatively severe seasonal temperatures and a consequent wide annual temperature range. The monthly temperature range varies from an average of about 30°F to 35°F in the summer to 26°F to 28°F in December and the early spring. The greatest daily range in temperature appearing in available records was 48°F in December. Surface winds and clouds reduce this amplitude, sometimes by half, and they can change the time of the extremes by an hour or two. During the summer the maximum temperature occurs around 1600 PST each day, and the minimum between 0400 and 0500 PST. In the winter the maximum occurs between 1300 and 1400 PST and the minimum between 0600 and 0700 PST. The minimum temperatures, varying from about 10°F to 45°F, tend to occur 24 to 36 hours after a cold front passage.

Tables 7, 8, and 9 present various surface temperature data; Table 10 is a complete surface w
and Appendix B present the temperatures of the upper-air by months and seasons from 5,000 through

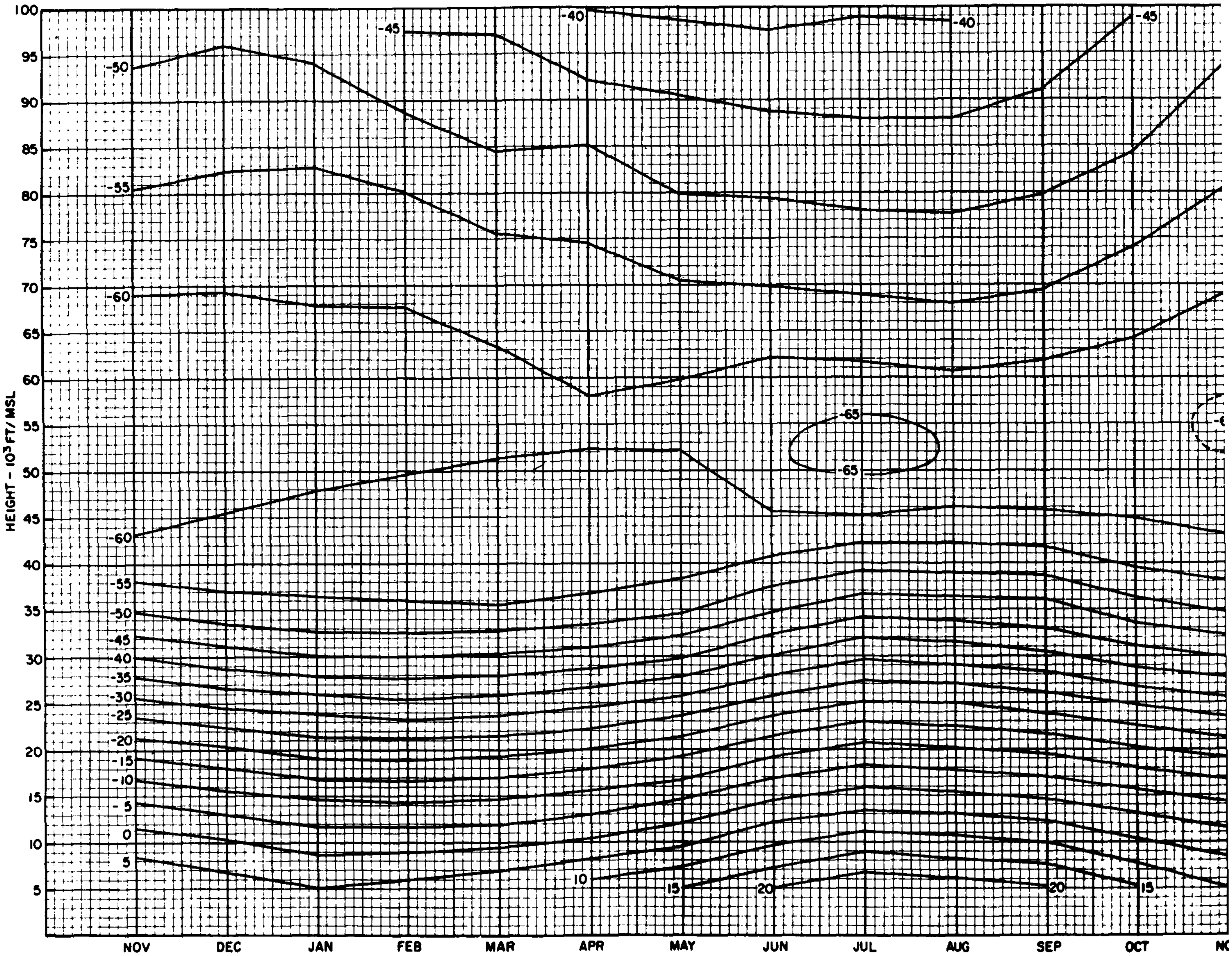

FIG. 1. Monthly Upper-Air Temperatures.

; various surface temperature data; Table 10 is a complete surface weather summary; Figs. 1 and 2
›eratures of the upper-air by months and seasons from 5,000 through 100,000 feet above m.s.l.

2

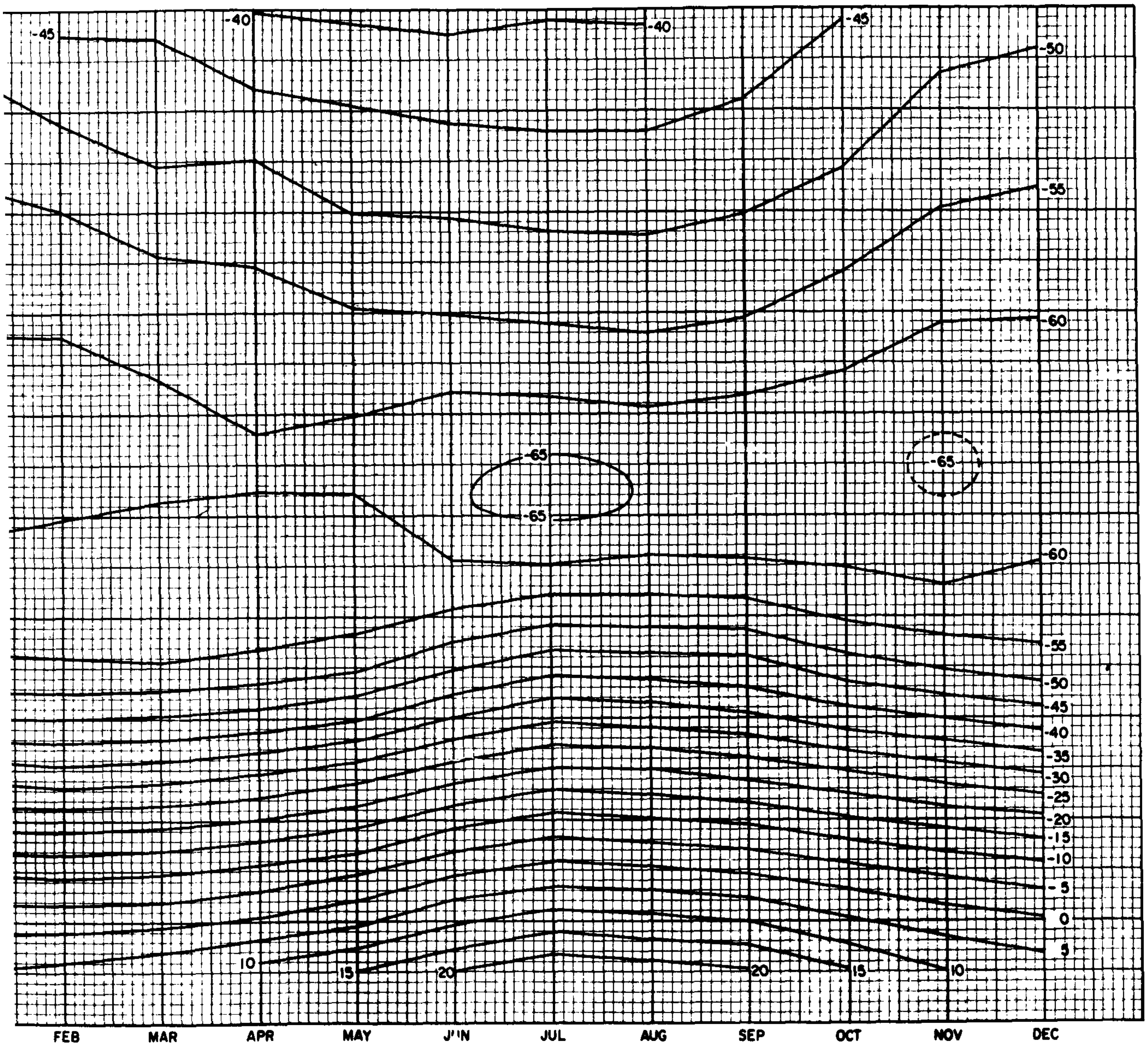

FIG. 1. Monthly Upper-Air Temperatures.

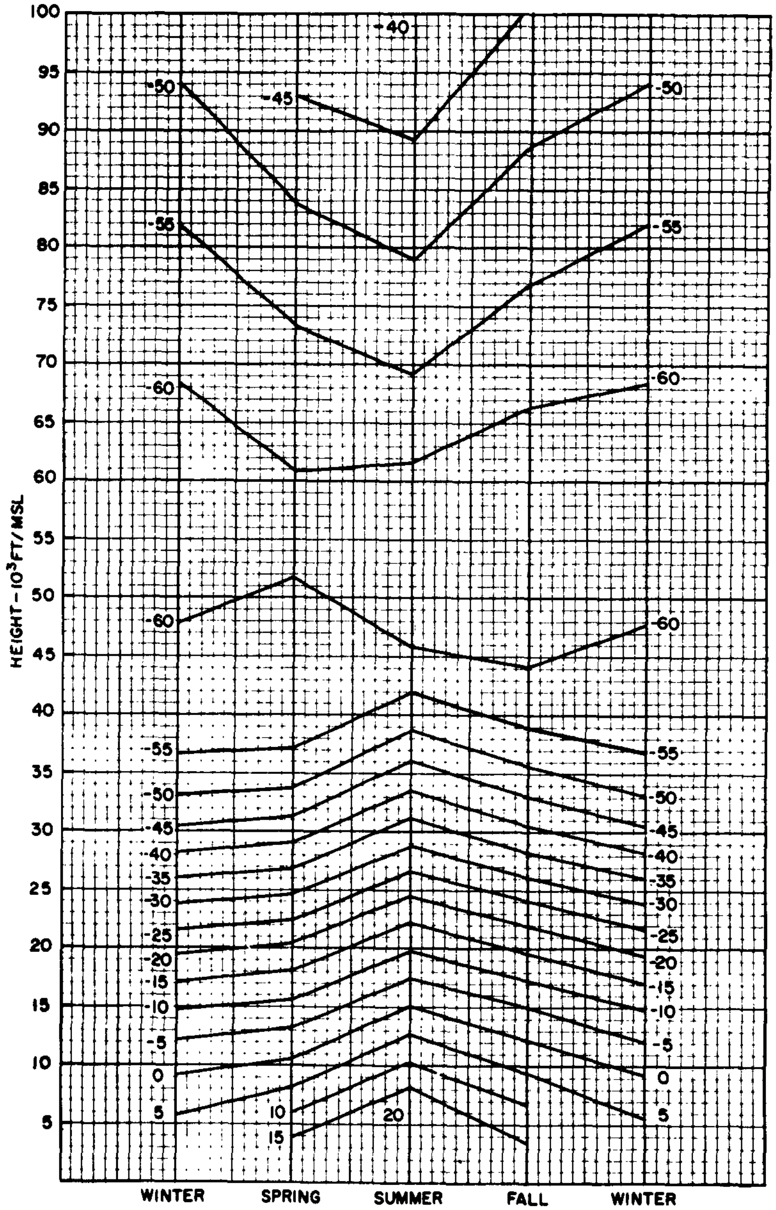

FIG. 2. Seasonal Upper-Air Temperatures.

TABLE 7. Temperature Summary, 1946-1962

	Highest (deg)	Date day/yr	Lowest (deg)	Date day/yr	Av. High (deg)	Av. Low (deg)	Mean (deg)	Av. Days/ Low of 32° or Less	Av. Days/ High of 100° or More
Jan	77	23/48	6	24/62	56.8	29.9	43.1	20.3	0
Feb	80	10/51 25/54	14	13/48	62.6	34.9	48.7	10.1	0
Mar	86	24/56	22	5/48 14/62	68.0	40.2	54.2	4.2	0
Apr	97	22,23/49 4/61	28	9/53	78.5	49.1	64.1	0.3	0
May	107	26/51	36	15/62	84.9	56.0	70.6	0	0.9
Jun	114	22/54 20,21/61	42	10/54	95.6	64.4	80.3	0	9.9
Jul	113	11,19/59 18/60	55	3/56	102.1	71.1	87.0	0	22.6
Aug	110	19/50 11,12/58 12/60 13,14/62	53	30/53 23/60	100.2	68.2	84.2	0	18.5
Sep	110	1,2/50 6/55	40	26,27/48	94.4	61.5	78.0	0	8.6
Oct	99	2/52	32	30/46	81.5	49.9	65.8	0.1	0
Nov	88	1/62	20	29/52 30/57	67.7	37.1	52.1	7.1	0
Dec	75	1,2,5/49 2/55 12/58	2	27/62	58.9	30.3	44.3	20.8	0
Year	114	6/22/54 6/20,21/61	2	12/27/62	79.3	49.4	64.4	62.9	60.5

TABLE 8. Number of Days in Which Temperatures Rose Above 95°F

	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	Mean
Apr	0	0	0	2	2	0	0	0	0	0	0	0	0	1	0	1	0	0.4
May	0	7	1	4	7	5	7	0	6	1	2	2	7	2	4	0	0	3.2
Jun	12	6	12	19	14	16	7	13	13	13	18	22	14	29	27	18	20	16.0
Jul	29	26	28	31	28	30	29	31	30	24	24	29	28	31	30	27	29	28.5
Aug	28	16	29	23	25	24	31	26	18	31	27	25	30	26	25	20	30	25.5
Sep	6	14	15	18	5	23	15	18	10	14	20	11	18	10	16	4	20	13.9
Oct	0	1	0	0	0	0	5	0	0	0	0	0	0	1	0	0	1	0.5
Year	75	70	85	97	81	98	94	88	77	83	91	89	97	100	102	70	100	88.0

TABLE 9. Degree Days, 1946-1962

Period	Degree Days*
January	-680
February	-462
March	-336
April	-101
May	31
June	0.8
July	0
August	0
September	1.4
October	70
November	-392
December	-641
Year	-2,715

*A degree day is 65°F minus the mean daily temperature, with negative values considered zero.

TABLE 10. Weather Summary, 1946-1962

MONTH	AVERAGE AIR DENSITY SLUGS/FT^3	STATION PRESSURE MILLIBARS	MEAN MAXIMUM TEMPERATURES	MEAN MINIMUM TEMPERATURES	MEAN TEMPERATURE	HIGHEST TEMPERATURE	DATE	LOWEST TEMPERATURE	DATE	GREATEST DAILY RANGE	AVERAGE DAILY RANGE	TOTAL HEATING DEGREE DAYS	DAYS MIN TEMPERATURE 32° OR LESS	DAYS MAX TEMPERATURE 100° OR MORE	MEAN TEMPERATURE OF DEW POINT	MEAN RELATIVE HUMIDITY	AVERAGE PRECIPITATION	GREATEST PRECIPITATION IN 24 HOURS	DAYS WITH PRECIP. 0.01 INCHES OR MORE	DAYS WITH THUNDERSTORMS	TOTAL SNOWFALL UNMELTED	DAYS WITH SNOWFALL	PREVAILING WIND DIRECTION	AVERAGE HOURLY SPEED	MAX VELOCITY M.P.H. (PEAK GUST)	
Jan	.00227	939.7	56.8	29.9	43.1	77	23/48	6	24/62	49	27	680	20.3	0	26	52	0.52	0.91	2.2	0.1	1.0	1.2	SW	6.5	77	[illegible]
Feb	.00224	938.1	62.6	34.9	48.7	80	10/51 25/54	14	13/48	49	28	462	10.1	0	27	47	0.37	0.75	1.9	0	0	0.2	SW	7.9	69	W
Mar	.00221	935.3	68.0	40.2	54.2	86	24/56	22	5/48 14/62	47	28	336	4.2	0	28	39	0.21	0.89	1.1	0.1	0	0	SW	10.5	81	W
Apr	.00217	934.1	78.5	49.1	64.1	97	22,23/49 4/61	28	9/53	50	29	101	0.3	0	32	33	0.13	0.88	1.1	0.4	0	0	SW	10.7	69	N
May	.00213	932.2	84.9	56.0	70.6	107	26/51	36	15/62	44	29	31	0	0.9	35	30	0.03	0.16	0.5	0.4	0	0	SW	11.1	66	[illegible]
Jun	.00209	931.5	95.6	64.4	80.3	114	22/54 20,21/61	42	10/54	45	31	0.8	0	9.9	39	24	0.02	0.29	0.2	0.2	0	0	SW	10.6	67	[illegible]
Jul	.00207	933.2	102.1	71.1	87.0	113	11,19/59 18/60	55	3/56	48	31	0	0	22.6	43	23	0.02	0.18	0.4	0.6	0	0	SW	9.9	66	[illegible]
Aug	.00208	933.4	100.2	68.2	84.2	110	19/50 11,12/58 12/60 13,14/62	53	30/53 23/60	45	32	0	0	18.5	42	25	0.03	0.35	0.4	0.6	0	0	SW	9.9	53	[illegible]
Sep	0.00211	933.4	94.4	61.5	78.0	110	1,2/50 6/55	40	26,27/48	51	33	1.4	0	8.6	38	26	0.15	0.68	0.9	0.2	0	0	SW	8.3	60	[illegible]
Oct	.00216	935.7	81.5	49.9	65.8	99	2/52	32	30/46	50	32	70	0.1	0	33	32	0.07	0.40	0.5	0.1	0	0	SW	8.1	66	[illegible]
Nov	.00223	939.2	67.7	37.1	52.1	88	1/62	20	29/52 30/57	52	31	392	7.1	0	29	43	0.33	1.03	1.2	0.1	0	0	SW	6.1	65	[illegible]
Dec	.00227	940.3	58.9	30.3	44.3	75	1,2,5/49 22/55 12/58	2	27/62	50	28	641	20.8	0	26	47	0.42	0.93	1.8	0	0	0.2	SW	6.0	71	[illegible]
TOTAL												2715	62.9	60.5			2.30		12.1	2.8	1.0	1.6				
AVG	.00217	935.5	79.3	49.4	64.4						30				33	35							SW	8.8		
EXTREME						114	22/54 20,21/61	2	27/62	52								1.03							81	W

TABLE 10. Weather Summary, 1946-1962

AVERAGE DAILY RANGE	TOTAL HEATING DEGREE DAYS	DAYS MIN TEMPERATURE 32° OR LESS	DAYS MAX TEMPERATURE 100° OR MORE	MEAN TEMPERATURE OF DEW POINT	MEAN RELATIVE HUMIDITY	AVERAGE PRECIPITATION	GREATEST PRECIPITATION IN 24 HOURS	DAYS WITH PRECIP. 0.01 INCHES OR MORE	DAYS WITH THUNDERSTORMS	TOTAL SNOWFALL UNMELTED	DAYS WITH SNOWFALL	PREVAILING WIND DIRECTION	AVERAGE HOURLY SPEED	MAX VELOCITY M.P.H. (PEAK GUST)	DIRECTION OF PEAK GUST	DATE	NO. OF DAYS CLEAR	NO. OF DAYS PARTLY CLOUDY	NO. OF DAYS CLOUDY	AVERAGE CLOUDINESS %	DAYS WITH HAIL	DAYS WITH BLOWING DUST	DAYS WITH FOG	HAZE
7	680	20.3	0	26	52	0.52	0.91	2.2	0.1	1.0	1.2	SW	6.5	77	SW	14/50	14.8	10.8	5.4	38	0	0.7	0.5	0.2
8	462	10.1	0	27	47	0.37	0.75	1.9	0	0	0.2	SW	7.9	69	W	22/48	13.7	10.2	4.3	36	0	1.6	0.4	0.1
8	336	4.2	0	28	39	0.21	0.89	1.1	0.1	0	0	SW	10.5	81	W	19/52	14.5	12.8	3.7	35	0	1.8	0.1	0.1
9	101	0.3	0	32	33	0.13	0.88	1.1	0.4	0	0	SW	10.7	69	N	2/57	16.1	10.9	3.0	31	0.1	1.2	0	0.4
9	31	0	0.9	35	30	0.03	0.16	0.5	0.4	0	0	SW	11.1	66	SW	23/62	20.2	8.9	1.8	26	0	0.9	0	0
1	0.8	0	9.9	39	24	0.02	0.29	0.2	0.2	0	0	SW	10.6	67	WSW	20/47	25.2	4.2	0.6	14	0	0.4	0	0
1	0	0	22.6	43	23	0.02	0.18	0.4	0.6	0	0	SW	9.9	66	NW	24/49	24.3	5.8	0.9	16	0	0.1	0	0
2	0	0	18.5	42	25	0.03	0.35	0.4	0.6	0	0	SW	9.9	53	ESE	11/53	26.4	3.8	0.8	13	0	0.6	0	0
3	1.4	0	8.6	38	26	0.15	0.68	0.9	0.2	0	0	SW	8.3	60	WSW. W	16/46 24/48	25.5	3.9	0.6	13	0	0.3	0	0
2	70	0.1	0	33	32	0.07	0.40	0.5	0.1	0	0	SW	8.1	66	NW	23/56	21.8	8.1	1.1	21	0	0.6	0	0
1	392	7.1	0	29	43	0.33	1.03	1.2	0.1	0	0	SW	6.1	65	SW	18/50	19.8	8.0	2.2	25	0	0.5	0.4	0.2
8	641	20.8	0	26	47	0.42	0.93	1.8	0	0	0.2	SW	6.0	71	SSW	4/53	16.0	10.9	4.1	34	0	0.5	0.9	0
	2715	62.9	60.5			2.30		12.1	2.8	1.0	1.6										0.1	9.2	2.3	1.0
0				33	35							SW	8.8				19.9	8.2	2.4	25				
							1.03							81	W	3/19/52								

Temperature Inversions. In the atmosphere during the daytime the temperature normally decreases with altitude. Because the heat absorbed by the air mass is distributed throughout the mass, and because water vapor retains this heat tenaciously, reradiation of the absorbed energy after sunset to outer space from the atmosphere itself proceeds relatively slowly.

However, the earth's surface acts differently. Heat is absorbed only into the few top inches of the surface because of its density and insulating qualities. As only a small amount of heat can be retained in such a small volume, this heat is quickly reradiated after sunset and the surface cools rapidly. In so doing it cools the air immediately adjacent to the surface, resulting in the phenomenon known as an inversion. In the inversion condition, the normal temperature distribution in the atmosphere is reversed and temperature increases with height from the ground to the top of the inversion.

The depth of the inversion depends on the mixing of air by wind movements. Very light winds or calm conditions are necessary to produce a deep inversion; strong winds near the surface which tend to mix the surface cold air with the warmer air above destroy the inversion. Fortunately, in the majority of cases, light winds prevail at night over the valley, producing a deep inversion at sunrise.

As the sun comes up, heating of the surface takes place and the inversion is slowly dissipated. Whether the inversion will dissipate completely or not depends upon the amount of surface cooling during the night and the amount of temperature rise during the following day. If the inversion is completely dissipated, continued surface heating will cause convective currents to rise, producing gusty winds and cumulus clouds, if sufficient moisture is present in the atmosphere.

Short wavelength radiation does not produce an inversion, no matter how sharp the moisture discontinuity. Furthermore, it has been found that the sharper the moisture discontinuity, the greater the heating at the base of the inversion.

Light winds help form a steep inversion of shallow height, while strong winds, by turbulent mixing, help form a weak inversion of great height or no inversion at all because the temperature loss is distributed over a greater height.

Both warm and cold fronts are inversions because cold air lies below warm air along a frontal surface. Moisture content as well as temperature normally increase with altitude through a frontal surface. Rain or snow, when falling first through a moist layer and then a dry layer, cools the dry layer sufficiently to create an inversion between the top of the originally dry layer and the base of the moist layer.

A steep lapse rate of temperature below an inversion is caused by one or more of several factors. In the first place, it is desirable that some wind and preferably a brisk breeze be present to keep the air parcels in continuous motion. In the absence of wind, very little stirring can occur. Vertical motions of particles are damped out by strong resistance, even in the presence of wind, when the air is too stable. A very strong wind over rough or even semirough terrain will redistribute the heat, lowering the temperature at the top and increasing it at the base of a layer of air, but the introduction of some other agent, such as the sun, greatly hastens the process. The sun heats the earth's surface and thereby warms the lower levels of any earth-contiguous air layers. A lot of wind in the presence of surface heat insures a well-defined layer of mixed air and practically guarantees an inversion aloft.

Pronounced inversions of temperature located below 5,000 feet above the surface are seldom the result of one factor. They are primarily inversions between a well-mixed surface layer of air and an unmixed higher layer, which have been strengthened by subsidence. Both factors operating simultaneously can create inversions from 10°C to 15°C in 1,000 feet, although the ordinary inversion is not this well defined. A single inversion-creating process operating alone never produces inversions as great as those resulting from the pressure of two or more processes operating simultaneously.

Inversions separating a surface layer of mixed air from a higher layer of unmixed air are higher in summer than winter but they are more prominent in winter than in summer. The reason for this lies in the fact that a high summer sun creates hot land which tends to send convection currents to high levels, thereby destroying inversions or raising them to great heights. Long nights and low daytime sun in winter months favor the maintenance of any inversion that might develop, even at surface levels.

Whenever the atmosphere is subsiding, an inversion develops within the sinking air. When the inversion nears the earth, it is enhanced by a mixed surface layer.

In these subsidence inversions, the sinking air heats due to compression as it nears the earth. If, therefore, a layer of air sinks down to a certain level and then flows laterally, all the heat that accumulates in the layer raises its temperature considerably above that of the layer immediately below. An inversion of temperature is inevitable between the heated layer and the cooler surface layer.

With a high pressure cell over the Great Basin, marked subsidence, accompanied at times by a very strong surface inversion, is typically evident in this region. The subsidence inversion usually is preceded by a northerly to northwesterly flow aloft, and is accompanied by a relatively light and variable wind condition aloft. The clear dry air occurring with this inversion is very favorable for radiation loss from the

surface during the night, together with low minimum temperatures. The absence of strong winds aloft during the dominance of the Basin High, and the low values of insolation during the winter months tend to maintain the surface inversion once it has formed.

The typical lapse rate in the early morning consists of an inversion in the lowest few hundred meters, above which is the normal decrease of temperatures with height. As the sun comes up, surface heating takes place and the inversion is slowly dissipated as convection creates a dry adiabatic lapse rate through a layer which increases in height until the time of maximum temperature. Whether the inversion will dissipate completely depends on the amount of surface cooling during the night and the amount of temperature rise during the following day. If the inversion is completely destroyed, continued surface heating will cause the lapse rate to exceed, sometimes greatly, the dry adiabatic lapse rate through the lower 200-300 feet.

Air passing from west to east over the Sierras causes formation of a turbulent leeside eddy. This causes surface winds on the lee side to become extremely gusty, creating strong turbulence aloft. Winds of this nature do not appear strong enough to prevent the surface inversion from forming during the hours after sunset. The radiation inversion, in turn, presents a barrier of stable air to the 30- to 35-mph gradient winds and prevents them from reaching the surface. The surface winds, however, will pick up after 0930 PST as the inversion is destroyed by daytime heating.

Changes in noise intensity of similar aircraft in flight can be caused by changes in the relative position of the aircraft with respect to the point of observation, and to the position of a regional temperature inversion.

Under normal convective conditions (clear sky), aircraft noise will be moderate. Its intensity will vary with relative motion of the plane in approximate accord with the inverse square law.

Under known inversion conditions, aircraft noise will be intense and will not vary with relative motion of the plane in accordance with the inverse square law or with any other simple law. The plane noise will be intense when the aircraft is below the inversion and will be almost undetectable when the aircraft is above the inversion. Quite similar conditions will be noted with low strata clouds.

Sudden cessation of aircraft noise will be noted when an aircraft, flying beneath an inversion, penetrates the inversion layer and rises above it.

Aircraft noise during inversion conditions can be reduced if the aircraft climbs to an altitude exceeding the height of the inversion as rapidly as possible after takeoff and then levels off instead of climbing gradually to cruising altitude.

Temperature-Caused Phenomena. (1) Dust devils: Conditions conducive to the formation and maintenance of dust devils are (a) relatively level terrain with loose surface material, (b) winds near the surface below certain (as yet undetermined) critical velocities, and (c) intense surface heating, with lapse rates near the surface greatly exceeding the dry adiabatic rate. The weather and terrain here in the valley are extremely favorable for the formation of dust devils.

Some texts give the mistaken impression that when the lapse rate exceeds the autoconvective rate (when density increases with height), convection and overturning will be initiated immediately without any external impulse. Both theory and observation show that this is not true. Lapse rates greatly exceeding the autoconvective rate have been measured during dust-devil and inferior-mirage conditions. The very fact that these inferior mirages are observed shows that near the surface there must be layers of air with lapse rates exceeding the autoconvective, and that these layers must be of appreciable horizontal extent.

Stability is usually determined by the acceleration produced on a test particle when it is given a vertical displacement from its initial position. However, if a layer of heated air near the surface is undisturbed, the lapse rate may exceed the autoconvective rate without convection taking place automatically. Any slight vertical perturbation could, however, be the trigger action for convection.

The standard theory for the formation of dust devils assumes that hot air near the surface breaks through the superadiabatic layers near the ground and rises in a columnar form. It is assumed that the incoming air is deflected to one side or the other of the rising air column, forming a whirl which may spin either to the right or to the left.

The times of occurrence of these whirls are usually from 1 to 5 hours before the times of maximum temperatures or between 1100 and 1500 PST with the most common period being from 1300 to 1400 PST. The probable reason for this is that wind speeds normally increase as the times of maximum temperatures are approached, and when certain critical speeds are reached, dust devils cannot exist. These critical speeds have not yet been determined but vary with lapse rate and other factors.

As to size, the dust devils may range in diameter from 20 feet to 200 feet, and in height from 10 to 4,000 feet with no consistent ratio between diameter and height.

Velocities in the dust devils are estimated to be from 6 to 10 Beaufort (25 to 63 mph). The rate of horizontal movement is about 5 to 30 mph. Maximum duration of a single dust devil is probably about 20 minutes. Rows of these whirlwinds may develop along the leading edge of steep cold fronts.

(2) Mirages and heat waves: Mirages occur when there are strong temperature contrasts in adjacent layers of air. The most common mirages are those in which there are deceptive appearances of water surfaces and those in which there are images of distant objects, both of which result from the observed images and the weather conditions causing the mirage. The common inferior mirage, producing either the illusion of a water surface or an inverted image, results from superadiabatic temperature lapse rates which cause a rapid increase of air density with height. This is a condition favorable for convection in which convection has not yet begun because of lack of turbulence and the slow transfer of heat by conduction and radiation. The apparent water surface is the image of the sky being reflected from the surface of this layer of superheated air. The eye of the observer must be somewhat above the heated layer in order to observe this phenomenon. In this type of mirage a distant object and its inverted image below it are sometimes seen. This effect is also caused by the heated layer of air acting as a reflector. Because the image is below the visible surface or real object, it is called an inferior mirage.

When there is a sharp temperature inversion with the consequent decrease in air density with height, there is sometimes produced a superior mirage in which a distant object and two images appear higher and closer to the observer than the actual location of the object, resulting in what has been called looming. An example of the multiple images would be the sighting of a building in the distance with another building floating above it apparently upsidedown, and above this still another building, upright in this case. These phenomena are due to gradual bending of light. We speak of layers of warm and cold air, but it should be understood that the transition from one layer to another is not abrupt. There is a mixing and a gradual change in the refractive power of the air, and the effects seen in mirages are due to this continuous variation. Complete stratification, with mirror-like bounding surfaces, does not occur in nature.

Although both superior and inferior mirages are common to this area, it is the inferior mirage which is characteristic of the valley where clear skies, dry air, and sandy soil frequently result in superadiabatic lapse rates. The heat from the hot desert surfaces added to the air causes a shimmering of the air which is always associated with the inferior mirage. This shimmering, called heat waves, results from the irregular variations of the density of the air associated with the processes of convection and vertical transport of heat. It is assumed that this vertical transport of heat will be sufficient to create shimmering only as long as a lapse rate equal to the dry adiabatic or less is maintained, in which case an increase of density with height will result.

Even under the most favorable conditions, the absolute maximum to which heat waves will rise is 2,500 feet.

Heat waves usually begin to be visible within a half-hour of the time the heating of the surface begins (approximately 0600 PST in the summer), and completely cease at the time cooling begins (approximately 1600 PST). During this time, the intensity increases from a very slight shimmer to maximum shimmer between 1200 and 1400 PST, and then decreases to a very slight shimmer again before the heat waves cease at about 1600 PST.

AIR POLLUTION

Particles or molecules of dust, smoke, and haze, originating at the surface of the earth, are carried from their source by parcels of air. If air parcels are unable to rise due to great stability of the air, the atmospheric pollution will be distributed horizontally but not vertically. Air pollution over the valley is produced by two different meteorological conditions: (1) blowing dust and sand caused by strong and turbulent surface winds, and (2) dust and/or smoke concentrated in the lower levels primarily in the winter months and in the early mornings when nocturnal cooling places an inversion on the ground and prevents all vertical motions of air. Under these conditions vertical distribution of the accumulated foreign particles cannot occur. However, should the air lose its stability sufficiently to permit its parcels to move both horizontally and vertically, each parcel will carry its share of pollution to higher levels, thereby decreasing the concentration of these substances along the earth. In thoroughly mixed air, all impurities are distributed uniformly in a layer extending upward to a level above which parcels cannot rise, i.e., a stable layer. An inversion is a stable layer of air which prohibits any and all vertical penetration by rising parcels; it therefore is the top of a layer in which there can be an equality in concentration of impurities, often indicated by a very definite and visible haze line, above which the air is clean and highly transparent.

Typical examples of this condition found in the local area are the smoke layers (noticed in the early morning hours) which are caused by the stratification of the smoke from the burning pits of the local dumps; the layers of dust to the west, caused by the sand and gravel company operations there, and the haze which, on occasion, drifts in to Indian Wells Valley from Owens Valley (the line of demarcation can usually be located only by a pilot flying through this haze layer).

Another condition--a winter situation--occurs when this area is dominated by a Great Basin High pressure system, which may persist for 3 to 5 days. This Basin High is accompanied by clear, subsiding dry air aloft and nearly calm winds at the surface during the nighttime. These conditions are favorable for considerable radiational surface cooling at night, resulting in the formation of a sharp temperature inversion from

the ground upward. The stratification in the lower layers is thus very stable, and therefore unfavorable to mixing processes that would distribute the pollution over a deeper layer. It has also been observed that early morning hour traffic in the valley stirs up dust, which cannot penetrate the inversion resulting in reduced visibilities for 2 to 3 hours after sunrise.

EFFECTS OF WEATHER VARIATIONS UPON WINDS ALOFT

Effects of Daily Weather Variations

During the night and in the early morning hours light winds generally prevail in the valley with frequent moderate to strong winds rising during the afternoon. These relatively high afternoon winds are caused by several factors. The high diurnal variations (daily fluctuations of temperature due to the succession of day and night) and resulting pressure gradient differentials are one cause. The high degree of surface heating in the area and the unstable lapse rate in the afternoon causes vertical air currents and dust devils. If sufficient moisture is present, these vertical air currents will cause cumuli-form clouds to form. These clouds, in turn, will cause uneven heating of the surface which will further aggrevate the situation.

Stability and instability of the air determines to a large extent the degree of wind increase over a crest of terrain (such as any of the surrounding mountains). Stable air resists vertical motions much more intensely than unstable air. Parcels of air in a layer of stable air traveling toward a mountain range will try to escape through the passes and will resist strongly any uphill motions imparted to them by the inertia of the layer as a whole. When the air is stable, therefore, wind velocities in the valley and passes is substantially increased. All the air which cannot be accommodated by either the valley or the passes must flow over the crests of terrain, where it will pass at the lowest possible level at a greatly augmented velocity. The net result of stability in air composing an uphill wind is a tendency toward increased velocities in the passes, throughout the valley, and near the surface along higher terrain, but with very little change in the velocity pattern a short distance above the mountain tops.

When strong winds pass over the mountain range, they cause the usual leeside turbulence but predominately in the higher levels, and then, due to increased velocity, pass over an area of relative calm, coming to earth some distance away. It is entirely possible for this stream of air to then bounce aloft once again and pass over still another area of light winds or calm. These conditions, which are very typical of this area during periods of a strong westerly or northerly flow of air passing over the Sierras, cause considerable turbulence as well as very erratic winds aloft.

Rough or mountainous terrain very frequently deflects air parcels much more than does smooth, even terrain. Winds will change direction as much as 80° to 90° if by so doing they can blow through a mountain pass or along the valley. If air parcels are forced to travel over the top of high terrain such as the mountain ridges surrounding the valley, previously mentioned eddy currents are created, and their velocity is substantially increased over a region centered on the greatest height of the elevated terrain.

On the other hand, unstable air does not resist vertical thrusts and exhibits little reluctance toward climbing a mountain or hill. In passing over mountainous terrain, an increase in velocity must occur, but will be distributed throughout the depth of the unstable layer. The total velocity increase is less, though it extends to greater heights than in the case of stable winds. Likewise, the valley and pass winds are not as strong.

Below the gradient level (the point at which the flow of air is not affected by surface friction) both wind direction and velocity are altered by the retarding effect of surface friction, whereas above this level the winds will be found to be fairly constant.

Seldom, if ever, does a surface wind blow with constant velocity or direction for intervals exceeding a minute or two. Under extreme conditions, velocity variations range from twice the average value to a near-calm, and direction variations describe an angle of 40° to 50°. Ordinary winds possess a velocity variation of about 50% and a direction variation of 20° to 30°.

A stationary circulation pattern will result in steady surface and aloft winds, but a traveling wind pattern will result in continuously changing velocities and directions. Gusts are present only when the pattern moves.

Anabatic and katabatic winds will have some effect on changing direction and velocity patterns. Anabatic winds are vertically rising winds resulting from instability and katabatic winds are shallow, but sometimes strong, surface winds blowing down hills. They result from nocturnal cooling of a shallow surface layer of air, and are not necessarily associated with a wind system.

Winds in the area are generally steady in direction when of significant velocity, with velocity usually varying according to thermal conditions, the strongest gusts ordinarily being associated with frontal passages.

Through the day, wind velocities tend to increase with heating and diminish after sundown. Rapid cooling, however, may give relatively high velocities throughout the night. Particularly active convective cloudiness during the summer may cause gusts of 40 miles per hour or more.

Effects of Seasonal Weather Variations

The local wind conditions reflect the stable atmospheric conditions and keep temperature inversions of the winter and spring months, with occasional strong cyclonic disturbances resulting in high winds during the period when the frequency of light winds is the greatest. During the summer and early fall months when pressure gradients are weak and cyclonic distrubances infrequent, light winds and very strong winds occur infrequently while winds with maximum speeds from 20 to 50 mph occur most frequently. Aided by strong thermal gradients, they reach their peak usually during the afternoon and evening. Light winds prevail during the early morning hours of this period. In general, extreme maximum speeds at levels below 10,000 feet m.s.l. occur in January and February, and through September, October, and November, while at higher levels, maximum speeds occur in March and April as well as in November and December. The months from July through October have low maximum wind velocities at all levels. With increasing altitudes above 5,000 feet m.s.l., minimum average speeds occur from June through September.

Below the 5,000-foot level, the prevailing wind direction shows the steering effect of the Indian Wells Valley topography in the large number of southeast and south-southeast winds during the summer and fall months, and north winds during the winter and spring months. The flow of air from the surface to 3,000-foot m.s.l. is predominantely from the south during the entire year as indicated by the prevailing direction of southwest at the surface for every month of the year and the prevailing direction of southeast at the 3,000-foot m.s.l. level for all months except November and December. At latitudes over 1,000 feet above the surface, the directions are west to southwest during the summer and west to northwest in the winter. (The northerly winter component results from the passage of troughs and low pressure centers.) The combination of pressure and temperature gradients and the orientation of the valley results in a normal backing of the prevailing wind to southeast at levels between 3,000 and 5,000 feet m.s.l. During the winter months, at higher levels, the prevailing wind backs (moves counterclockwise) through north to west, and during the summer months it veers (moves clockwise) through southwest to west. Peak velocities occur in December and January, the period of largest pressure and temperature differentials. There is a secondary maximum in March, when winter storms are still occurring, combined with the beginning of seasonal heating. Occasionally winds of gale force occur during periods of strong frontal activity.

In general, the prevailing surface direction is south-southeast beginning at 0900 PST. The southwest flow becomes dominant between 1400 and 1500, from March through July, and between 1600 and 1700 for the balance of the year. These effects appear to be the result of a combination of steering by the mountain passes plus mountain-valley thermal variations. The generally higher terrain to the west, and the passes southwest of the Station cause predominantly southwest flow. The strong

heating in the valley during spring and summer months is probably the cause of the earlier change to southwest winds during that period. Relatively stronger heating during morning hours on the mountain slopes west of the Station causes a thermal low in that area resulting in a temporary southeast flow.

Effects of Other Phenomena

Whenever there is a strong westerly flow over the Sierras, wave conditions may develop over the Station, and wind velocities recorded between 3,000 and 5,000 feet above the surface may well be erratic due to the turbulent mixing between the surface flow, which is conditioned by the valley contours, and the upper air flow. In a wave condition, this would be the area of the roll clouds and one of pronounced turbulence and marked downdrafts. Wind velocities would increase gradually until the main wave flow is reached at about 8,000 feet above the surface (slightly above the height of the Sierras) and then rise rapidly. Under wave conditions in this area, there appears to be a layer of updraft to about 4,000 feet followed by predominating downdrafts from 4,800 to 8,000 feet, with the main updraft from 8,000 feet to 15,000 feet, and a secondary updraft from 19,000 to 23,000 feet. The horizontal wind velocities are believed to be greater in the updrafts than in the downdrafts.

THE MOUNTAIN WAVE AT NOTS

While the Sierra Wave, in the Owens Valley region, has been so identified only in the last 30-odd years (Symons, 1928), it is probably one of the most striking and intense examples of the mountain wave phenomenon. This is particularly true in respect to strength and extent of the actual vertical currents. In fact, the world's altitude records for both single- and two-place sailplanes were set in the currents generated by this wave. On December 30, 1950, Ivans soared to 42,100 feet, and on March 5, 1951, Symons and Kuettner soared to 38,650 feet in a two-place sailplane. An unusual development of the vertical currents associated with the mountain wave occurred on March 5, 1950, enabling Bob Symons of Bishop, California, to attain an altitude of over 30,000 feet with both propellers of his P-38 feathered. He reported that "The upward air currents were at times as great as 8,000 ft/min". Such currents, with accompanying severe turbulence, could obviously have serious effects on aircraft entering the area if the pilot were unaware of the wave conditions.

The strongest waves develop when wind direction is nearly normal (or within 45° of perpendicular) to the axis of the Sierra. However, some scattered or isolated wave clouds do appear when the wind is in other directions. These are probably due to the action of individual peaks. During these strong wave conditions a wave cloud extending the

length of the Owens Valley, and sometimes stretching from Inyokern to the Mono Lake area north of Bishop, is usually present. The western or windward edge of this cloud will be parallel to the front of the Sierra; its width or downwind dimension will vary from a few hundred feet to several miles, depending upon the intensity of the wave. Carroll Wilson, of NOTS, in a similar study indicated that "to produce a significant updraft, the velocity of the wind at the mountain crest must be near 30 knots or more as measured under stable air conditions" (small temperature lapse rate).

Kenneth Colson determined that, "On days with no wave activity the average wind speed (normal to the Sierra) in the 10,000- to 18,000-ft layer was 9 knots, the speed increasing slightly with height. On days when the wave was of moderate intensity the average wind speed in this layer was 28 knots, and vertical wind shear was greatly increased. On the days with strong wave activity the average speed increased to 41 knots, and the shear was considerably greater".

The various lee waves which have been observed have a great variety of forms and intensities. The form which is perhaps best known and which is characterized by the Sierra Wave is the mature, strongly-developed wave. Visually the mature wave generally presents (1) one or more decks of altocumulus lenticularis wave or arch clouds at roughly 25,000 and 40,000 feet (although these clouds have been estimated to occur as high as 60,000 to 70,000 feet), (2) a dense cumuliform roll cloud, or rotor, at about 15,000 to 18,000 feet, (3) the föhn-gap (the clear region upwind of the wave clouds), (4) the strato-cumulus cap-cloud, or föhnwall, covering the Sierra, and (5) a "cloud waterfall" marking the downdraft over the Sierra slope.

While the unique cloud formations of the lee wave provide one means of estimating the amplitude or intensity of the flow pattern (but not an infallible one, because small clouds do not always mean a weak wave, and strong waves occasionally exist with no clouds at all), another and sometimes more reliable method of defining the wave intensity is to study the phenomena experienced by aircraft. In a mature wave the horizontal and vertical wind speeds are great. The updrafts extend to very high levels, and are generally stronger than the downdrafts, although the downdrafts cover larger areas. The updraft shows its effects at all altitudes, and it remains motionless with respect to the terrain and does not drift with the wind as do thermals. The strongest updrafts occur just upwind of the clouds, and the strongest downdrafts just downwind of them. These currents frequently have vertical speeds of 2,000 to 5,000 ft/min. Down currents of extreme violence are found close to the lee side of the mountains and are sometimes indicated by the descending portion of the cap cloud.

Although vertical movement of the air during wave activity is of greater importance from a flying-safety standpoint, the horizontal movement is more noticeable due to the fact that it is traveling in a constant direction.

Under wave conditions the most extreme turbulence generally occurs from the mountain crest level downward (on the lee side of the mountains), but heavy turbulence may be experienced up to a point about 50% higher than the difference in altitude between the valley floor and the mountain crest. Over the Sierra, this would be an altitude of 18,000-19,000 feet. The air is generally quite smooth above the roll cloud (extremely turbulent cloud formed on the lee side of the mountain at the approximate crest level), although it may be ascending or descending rapidly. When flying, it is generally advisable to avoid the vicinity of this and other low clouds, since the most violent turbulence is usually found in this region, especially below the roll cloud. If it is ever necessary to fly into the roll cloud, the flight should be made downwind, only at low speeds, at an acute angle to the cloud front and through the thinnest or most broken region, in order to minimize the sharp-edged gust effect. Gust load factors as high as 5.5 g have been experienced by gliders, and in one case of record, a sailplane, stressed to withstand 14 g, was torn apart in a flight through a rotor cloud at Bishop. However, soaring pilots have repeatedly reported that the main wave flow is very smooth in the updraft, while the downdraft may be very turbulent, particularly near the lee side of a lenticular cloud.

Most of the waves that occur are of lesser intensity and extent than those described above. Sometimes a moderately strong mountain lee wave exists but is not indicated by clouds, at other times the phenomenon may be confined to certain portions of the Sierra crest, and at still other times the wave motion may be detected only in the lower layers of the atmosphere. These variations in strength and appearance have been typed according to an arbitrary classification based upon visual observations and aircraft experiences, as follows:

Wave Intensity	Description
Strong	Roll and wave clouds, föhnwall, gap, "cloud waterfall"; strong up- and downdrafts.
Moderately Strong	Same as above but of lesser magnitude.
Moderate	Broken, local, or "dry"; maximum lift confined to regions, not extending along whole crest.
Fair	High or shallow, confined to either high levels or to rotor zone, with either roll or high clouds present, but not both.
Weak	Transitory, changing rapidly; weak updrafts.
Poor	No perceptible wave.

JET STREAMS OVER NOTS

An investigation of the seasonal occurrence of the jet stream over the Station, using speed criteria of 80 knots or more for fall, winter, and spring, and 40 knots or more for summer, showed that the mean height of the jet core in winter and spring was 2,000-3,000 feet below the mean height of the polar tropopause. Sharp temperature and density differences in an air mass would be expected near this level. In summer, the mean height of the jet core was 1,000 feet below the mean polar torpopause.

The prevailing winds in winter and spring were WSW to W at 102 knots. Thus, peak winds are usually associated with the passage of an upper trough. In summer, the prevailing jet-core flow was SSW to W at 60 knots. The swing to the south and lower speed are associated with the seasonal decrease in outbreaks of polar air. Jet streams of 80 knots or more occurred infrequently in the fall, indicating the usual stable local weather situation before the beginning of winter storms.

Jet streams are of particular interest and significance in local forecasting because of their intensifying effect on cyclonic development. The results of a frequency study made by comparing surface weather phenomena with the associated jet stream, by season, are shown below.

Season	Jets	No. Cases	Cloudiness Broken or more			Wind 35 knots or more		10 knots or more	Precipitation
			Low	Middle	High	S-SSW	SW-W	NW-N	
Winter	NW-NE	25	0*	4	28	0*	4	12	0*
	S-WNW	38	32	45	37	3	13	0	34
Spring	NW-NE	28	4*	4	14	0*	7	18	0*
	S-WNW	47	28	26	40	15	39	4	17

*Frequency of occurrence in percent.

Jet-stream occurrence was classified directionally into two groups, one for winds S to WNW, one for winds NW to NE. Low and middle cloudiness with northerly winds was very infrequent and precipitation did not occur. This is to be expected, since northerly winds would ordinarily blow only behind a front or after an upper-trough passage. The analysis was limited to winter and spring because fronts and upper troughs seldom pass the Station in summer, and the jet stream is found only infrequently in fall. Figure 3 is a graph showing annual mean wind speed over NOTS.

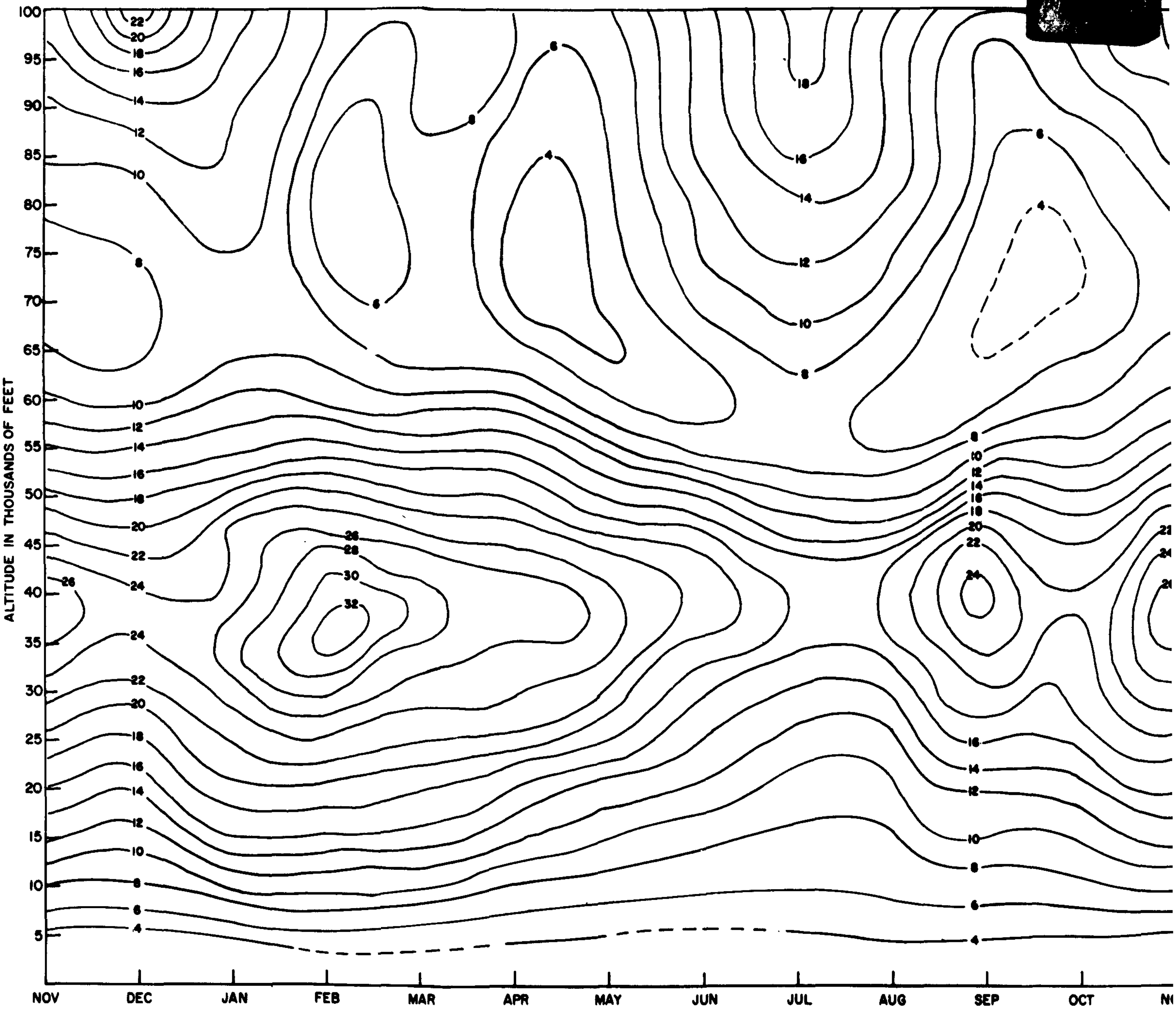

FIG. 3. Annual Mean Wind Speed.

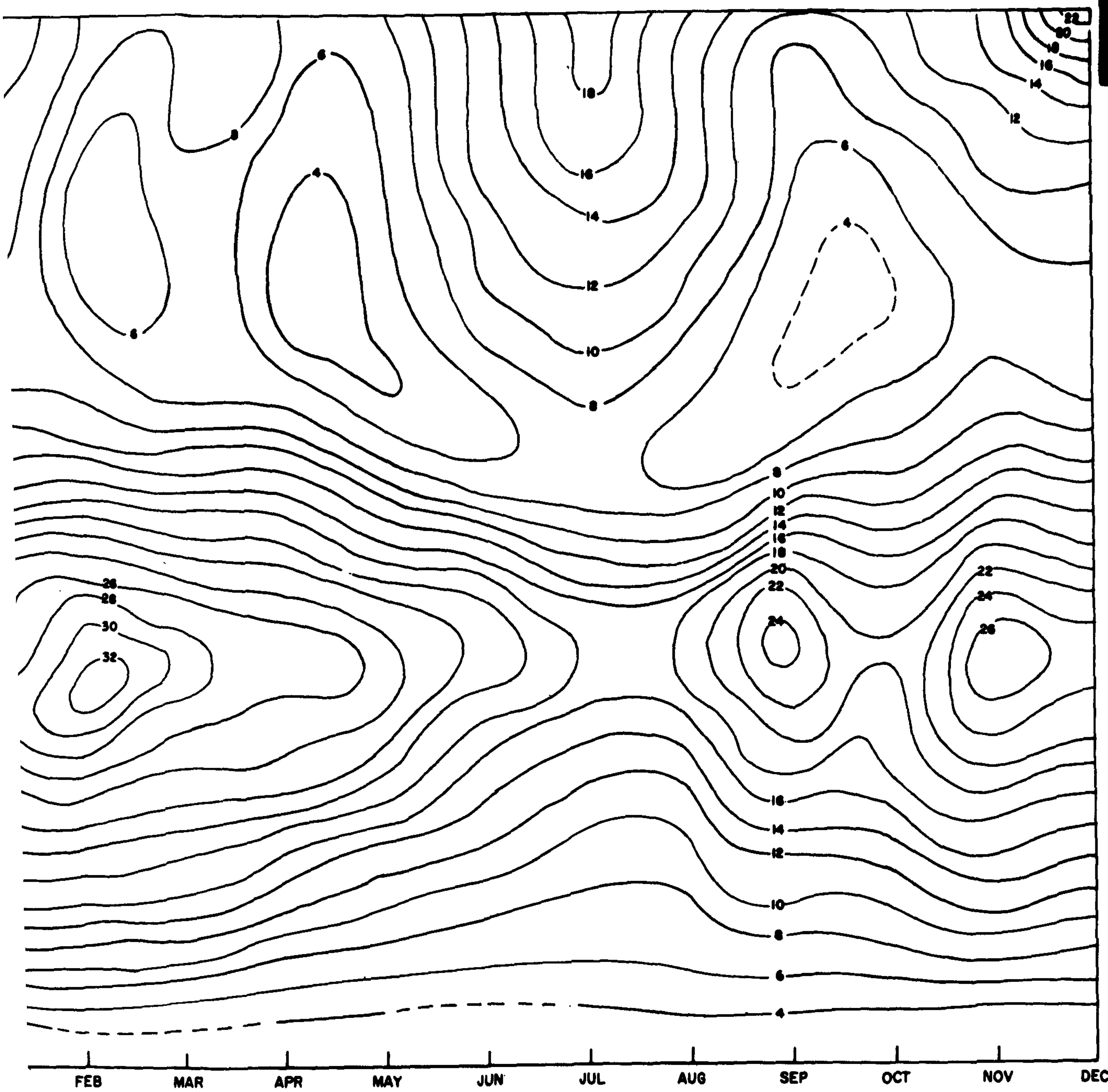

FIG. 3. Annual Mean Wind Speed.

TROPOPAUSES OVER NOTS

At one time or another there will be found over NOTS at least three more-or-less distinct tropopauses. These may be present either individually or together, and on occasion may overlap for short distances to produce double or complex tropopauses. These tropopauses are the arctic, polar*, temperate, and tropical. These tropopauses may be found at the following heights (m.s.l.) with the indicated potential temperature (Θ): the arctic from 30,000-33,000 feet with a Θ from 315-335°A; polar, 37,000-43,000 feet with Θ 330-350°A; temperate, 45,000-50,000 feet with Θ 365-375°A; and tropical, 53,000-55,000 feet with Θ 400-410°A.

The following table shows the seasonal averages of the tropopause heights (in ft/m.s.l.) and potential temperatures (in °A) for the NOTS area only:

Season	Arctic		Polar		Temperate		Tropical		First Leaf	
	Height	Θ	Height	Θ	Height	Θ	Height	Θ	Height	Θ
Winter	31,659	319	38,028	334	45,510	372	53,646	407	59,883	446
Spring	31,936	320	38,790	336	45,334	371	53,764	410	60,792	453
Summer	32,278	332	41,973	347	48,884	371	54,708	401	60,290	442
Fall	32,411	327	39,981	342	47,896	373	54,031	403	58,670	434

Wind Patterns and the Tropopause

Wind flow at and near each tropopause level above NOTS was analyzed by seasons, with the following results:

Arctic tropopause data was so scant that results were considered to be indicative rather than representative. Winds around the polar tropopause show little change in velocity through that level. There is a decided decrease in overall speed in summer, and the direction is then more southerly. In the fall, the trend is back toward the winter pattern.

In the region of the temperate tropopause, there is little change in wind direction through it during winter and spring, but there is a gradual decrease in speed. Again there is a sharp drop in speed in the summer, with an easterly flow beginning above the tropopause. The trend reverses in the fall.

*In this report, the polar tropopause (which is sometimes divided into a northern and a southern section, both sections often being considered independently) will be considered only the northern section.

Near the tropical level, the decrease in wind speed through the tropopause in winter and spring becomes more pronounced. The main feature of the summer pattern is the decided easterly component above the tropopause. The direction becomes westerly again in the fall.

Winds above and below the main tropopause leaf are comparatively light throughout the year, indicative of relatively higher temperatures and low densities. The flow is generally easterly both above and below the leaf-level in the summer, turning westerly in the fall.

Weather Situations and Tropopause Heights

An investigation of the relationship between local weather situations and the lowest tropopause heights indicated that there is a general correlation between tropopause height and the occurrence of a surface or upper front, or a trough or closed low at the 700- or 500-millibar level within 200 miles of the Station. Fronts or upper troughs 200 miles distant in a westerly direction are likely to pass the Station. Due to the local terrain and the lee-side low effect of the Sierras, such fronts and troughs may also still affect the Station's weather when 200 miles or more to the east. The fronts involved are almost always cold, or cold occlusions, since warm-front occurrence is locally infrequent. In the analysis, the summer months were not considered because fronts and upper troughs rarely occur in that season. A seasonal grouping of fall (October and November), winter (December, January, and February), and spring (March, April, and May) was used.

It was found that, in the fall, the mean height of the lowest tropopause was approximately 2,000 feet lower than normal when fronts or upper troughs were within 200 miles of the Station. During winter, this difference increased to 2,500 feet, in spring it was 3,500 feet. For exact figures on local weather situations and tropopause heights, see the tabulation below:

Mean Heights of Lowest Tropopause

	No. Cases	Fronts within 200 miles	No. Cases	Fronts near NOTS
Fall	25	35,809	58	37,606
Winter	64	34,177	101	36,662
Spring	85	35,319	121	38,960

The larger difference in spring is to be expected because outbreaks of cold air and near-winter temperatures still occur, combined with the beginning of seasonal heating.

HAZARDS TO FLYING

Flying hazards are present in this valley even though many good flying conditions prevail throughout the year. During the heat of the day, mainly in spring and summer months, the superadiabatic cooling during the daylight hours gives rise to turbulent dry thermal currents, often as high as 7,000 feet above the runways, making landing hazardous. In addition to the turbulent effect caused by the thermals over the area, the heat radiation waves on the runways tend to distort the pilot's vision. Other related hazards are relative humidities as low as 10%, which hamper engine performance; low air densities, which make longer runways for takeoff necessary; and absorption of heat by metallic fuel lines, which cause vapor locks. During the afternoon hours in the summer, aircraft usually encounter moderate turbulence below 10,000 feet above mean sea level over the valley, and in extreme cases near the mountains to the west, turbulence is encountered below 15,000 ft/m.s.l. When the valley is under the influence of a strong northerly pressure gradient on the surface and aloft, the consequent strong northerly surface winds blow alkali dust down over the valley from dry lake beds, located 30 to 40 miles north of the valley, reducing visibilities as low as 1/2 to 1-1/2 miles, thus causing a serious flying hazard. As strong downdrafts and strong turbulence are present near the high mountain ranges west of the valley it is advisable to warn light aircraft against flying in this vicinity of turbulence. Due to heat expansion of gasoline, which results in overflow aboard aircraft, it is recommended never to gas the aircraft to capacity at any time during the summer months. The recommended times for flight operations in this valley during the summer months are the hours from sunrise to 1100 PST. The rough terrain of this area causes extreme turbulence which is conducive to carburetor ice formation.

Appendix A

FACTORS CONTROLLING MOVEMENTS OF SURFACE PARTICLES

It is generally recognized that particles, initially at rest on the ground surface, are moved by one of two processes or a combination of the two. When the air moves past a particle, it may exert a viscous drag sufficient to move the particle. This initial motion will be in the direction of the wind, generally horizontal. The particle may simply roll and slide along the surface or it may become airborne by bouncing off an irregular surface formation.

The second process of particle removal from the surface depends upon surface impingement of previously airborne particles which have acquired considerable kinetic energy from the free-air stream during their time of flight. When these particles impinge upon the surface, they may (1) bounce back into the air stream as the result of an elastic collision, (2) shatter from such collision, (3) slide along the surface, (4) dislodge other particles, (5) be absorbed in the surface with no further particle movement, or (6) chip off pieces of massive surface elements, which pieces in turn may continue in motion. The term saltation has been applied to the jumping action of particles, and the term abrasion has been applied to the wearing away of larger surface elements by impact from saltation. Maximum erosion rates are experienced when both drag and saltation processes are operative, and, in general, erosion increases downwind from the upwind edge of an erodible surface.

Once a particle is dislodged from its resting place, it moves: (1) by sliding or rolling along the surface (this mode of transport is called surface creep); (2) by leaps and bounds, i.e., in short flights (this mode of transport has already been defined as saltation); or (3) by becoming airborne and being carried over appreciable distances before settling out of the free-air stream (this mode of transport is often termed suspension).

The mode of transport depends primarily upon the magnitude of the vertical air motions near the surface and the mass and size (or terminal velocity) of the particle. The largest erodible particles tend to move by surface creep, the intermediate particles by saltation, and the smallest particles by airborne transport. The general limits of particle size for natural sand and dust are:

Surface creep	$>1{,}000\ \mu$
Saltation	$50 - 1{,}000\ \mu$
Airborne	$<50\ \mu$

However, changes in the intensity of the vertical motions make these limits extremely variable.

The height to which small airborne particles may be lifted is limited only by the vertical exchange capacity of the atmosphere; while particles moving in saltation generally remain within a few feet of the ground. Thus, a large percentage of the mass of eroded material transported by the atmosphere is carried near the surface.

Theoretical studies and experimental results have shown that wind erosion of soils is related to a large number of atmospheric and surface properties. Below are listed the main factors which influence erosion by wind.

SURFACE PROPERTIES

A. Large-scale surface roughness
   1. Mechanical turbulence
   2. Overall sheltering
B. Small-scale surface roughness
   1. Sheltering of individual particles
      a. Percent of area covered by nonerodible aggregates or obstacles
      b. Orientation of obstacles
      c. Stability of aggregates against abrasion and disintegration by moisture and weathering
C. Area of erodible surface
D. Vegetable cover
   1. Live vegetation
   2. Plant residue
E. Cohesiveness of individual particles
   1. Moistness of surface
   2. Binding action of organic materials

The state of the surface has a profound effect upon the erodibility of particles which lie on that surface. These effects are manifest in the generation of mechanical turbulence in the air stream next to the surface and in the reduction of wind speeds and consequent sheltering of erodible particles. Recognized first of all are the relatively large roughness elements such as trees and structures, and terrain features such as hills and valleys. Trees and shrubs provide lee-side sheltering and are generally quite effective in combating erosion.

The second class of roughness elements is composed of clods or aggregates of soil, rocks, and small obstacles which provide lee-side protection for only a small area. These obstacles are highly important in erosion considerations since they may be numerous and be arranged in either a random fashion or, as in the case of small furrows and ridges, they may provide protection from preferred wind directions only. The

stability of soil aggregates against abrasion by impinging particles against the actions of wetting, drying, freezing, and thawing is a prime consideration in predicting the erodibility of a surface area.

Another factor which influences wind erosion to a marked degree is the downwind extent of the area subject to erosion. On an isolated erodible surface, the rate of soil flow increases from zero at the upwind edge to a rate which, if not controlled, is limited only by the carrying capacity of the wind. Considerable control of the erosion rate can be accomplished if the eroding surface is interrupted with strips of a noneroding surface (for instance, alternate strips of fallow and wheat stubble).

Small-plant cover is also effective in reducing erosion and is widely used for erosion control. Particles which lie under an appreciable plant cover are not susceptible to wind erosion. Plant residue also provides excellent protection against erosion.

Surface moisture content must be considered in connection with erosion since individual particles are easily cemented into nonerodible aggregates by wetting. Even surfaces which are extremely susceptible to erosion when in a dry state become essentially nonerodible when the surface is damp. Organic materials in the surface may also bind the particles, although this effect is generally temporary.

PARTICLE PROPERTIES

A. Particle size-frequency distribution
   1. Ratio of erodible to nonerodible fractions
B. Particle density
C. Particle shape

The particle size-frequency distribution of the erodible fractions of the surface soil exerts a profound effect upon the erodibility of that surface. For example, a smooth surface of only submicron particles is nonerodible in the presence of gale intensity winds but when submicron particles are mixed with particles 5 to 50 μ in diameter the surface becomes highly erodible.

Particle density also affects the erodibility of a soil except in the unlikely instance of a surface composed completely of particles less than 100μ in diameter. The particle density and shape are critical in the speed of individual particles and their removal and transport once they are airborne.

METEOROLOGICAL FACTORS

A. Wind velocity distribution in the surface layer
    1. Mean wind speed
    2. Wind direction
    3. Frequency, period, and intensity of gusts penetrating to the surface
        a. Vertical wind profile
        b. Transient and steady drag of the wind on the ground surfaces
    4. Vertical turbulent exchange
        a. Temperature stratification
        b. Surface roughness

B. Moisture content of the ground surface
    1. Precipitation
    2. Dew and frost
    3. Drying action of the air
        a. Relative humidity
        b. Solar heating

Meteorological factors enter into the erosion problem in two ways: (1) Antecedent weather determines to a large extent the "weathering" of a surface which renders that surface erodible, and (2) current meteorological conditions provide the motivating forces which initiate and sustain erosion. Since the erosion phenomena are confined to the surface layer, except for airborne transport of particles, the motion and state of the atmosphere next to the surface are of prime importance.

The mean wind speed is a useful measure of the basic energy supply available for erosion and the wind direction must be considered in relation to the orientation of roughness elements, slope of the land, and shape and size of the erodible land area. However, the primary paramaters of air motion in this problem are the frequency, period, and intensity of gusts which penetrate to the surface, and the transient stresses exerted on the surface particles by these gusts. Erosion is not, in general, a steady-state process and the selective action of turbulence elements in this process is greatly in need of clarification.

The transfer of eroded particles into the free-air stream depends upon the vertical turbulent exchange, or the vertical motions of the air. Since temperature stratification is one of the primary controls in vertical transfer phenomena, the vertical temperature distribution must be included in any consideration of particle erosion. The transport of particles to considerable heights is greatly aided by the occurrence of sustained and organized vertical motions of the atmosphere in thermal circulations. Such sustained vertical motions are generally absent during nocturnal hours, and this fact gives rise to a distinct diurnal cycle in atmospheric transportation of eroded particles.

Finally, meteorological phenomena such as precipitation, dew and frost, relative humidity, and solar heating all have an effect on the surface moisture content. The surface of the ground may go from a non-erodible state of dampness to a dry, erodible state in a few hours.

Appendix B

MEAN ATMOSPHERIC DATA TO 100,000 FEET ABOVE MEAN SEA LEVEL

5,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft³ times 10⁻⁵)	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	237	237	237	127	127
Mean	848	5.0	206	SSW or NNW-NNE	3.9
February					
No. Cases	234	234	234	115	115
Mean	848	6.5	205	N or SW	4.0
March					
No. Cases	279	279	279	152	152
Mean	847	8.8	203	SW or N	4.4
April					
No. Cases	282	282	282	129	129
Mean	846	12.2	200	N or SSW	3.9
May					
No. Cases	309	309	309	189	189
Mean	845	15.7	198	N or SE-SW	4.0
June					
No. Cases	304	304	304	172	172
Mean	846	20.5	194	N or S-WSW	4.4
July					
No. Cases	323	323	323	132	132
Mean	848	24.1	192	S-SW	3.5
August					
No. Cases	289	289	289	148	148
Mean	848	23.2	193	S-SW	3.8
September					
No. Cases	302	302	302	139	139
Mean	847	20.9	194	N or SSE-SW	3.9
October					
No. Cases	290	290	290	142	142
Mean	848	15.9	198	N	3.8
November					
No. Cases	255	255	255	119	119
Mean	849	10.4	202	NNW-N or SSW	3.5
December					
No. Cases	214	214	214	119	119
Mean	850	7.6	204	N-NNE	3.7
Winter					
No. Cases	685	685	685	361	361
Mean	849	6.3	205	NNW-N or SSW	4.0
Spring					
No. Cases	870	870	870	470	470
Mean	846	12.4	200	N or S-SW	4.1
Summer					
No. Cases	1218	1218	1218	591	591
Mean	847	22.2	194	S-SW	3.9
Fall					
No. Cases	545	545	545	261	261
Mean	848	13.3	200	N-NNE or SSW	3.7
Annual					
No. Cases	3318	3318	3318	1683	1683
Mean	847	14.9	198	N or S-SW	4.0

10,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	236	236	236	127	127
Mean	702	-1.8	175	W-WNW	9.6
February					
No. Cases	234	234	234	115	115
Mean	702	-1.5	175	NW-N or SW-W	10.1
March					
No. Cases	279	279	279	153	153
Mean	701	-1.1	174	W-NW or N	9.4
April					
No. Cases	278	278	278	129	129
Mean	702	1.0	173	WSW-WNW or N	7.6
May					
No. Cases	305	305	305	187	187
Mean	704	4.3	171	S-WSW	6.8
June					
No. Cases	304	304	304	173	173
Mean	706	9.6	169	S-WSW	6.2
July					
No. Cases	321	321	321	134	134
Mean	710	12.8	168	S-WSW	6.0
August					
No. Cases	289	289	289	148	148
Mean	709	12.0	168	S-SW	6.4
September					
No. Cases	300	300	300	139	139
Mean	708	9.7	169	S-W	6.8
October					
No. Cases	290	290	290	141	141
Mean	706	5.9	171	NNE-NE or WSW-WNW	6.9
November					
No. Cases	255	255	255	120	120
Mean	706	2.8	173	NW-NNE	7.9
December					
No. Cases	214	214	214	122	122
Mean	705	0.7	174	N-NE or W-WNW	8.4
Winter					
No. Cases	684	684	684	364	364
Mean	703	-0.9	175	W-NW or N-NNE	9.4
Spring					
No. Cases	862	862	862	469	469
Mean	702	1.5	173	WSW-WNW or N	7.9
Summer					
No. Cases	1214	1214	1214	594	594
Mean	708	11.0	168	S-WSW	6.4
Fall					
No. Cases	545	545	545	261	261
Mean	706	4.4	172	NNE-NE or WNW	7.4
Annual					
No. Cases	3305	3305	3305	1688	1688
Mean	705	5.0	171	WSW-W	7.6

15,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	234	234	234	125	125
Mean	578	-10.3	148	SW-NW	15.6
February					
No. Cases	232	232	232	109	109
Mean	578	-11.2	149	WSW-N	15.2
March					
No. Cases	273	273	273	149	149
Mean	577	-10.4	148	W-NNW	15.1
April					
No. Cases	270	270	270	127	127
Mean	579	-8.5	148	WSW-NNW	12.4
May					
No. Cases	293	293	293	184	184
Mean	581	-5.7	147	S-W	10.3
June					
No. Cases	299	299	299	166	166
Mean	585	-0.7	145	SSW-W	8.8
July					
No. Cases	304	304	304	132	132
Mean	590	1.8	145	S-WSW	7.8
August					
No. Cases	283	283	283	148	148
Mean	589	1.1	145	S-SW	7.6
September					
No. Cases	297	297	297	137	137
Mean	587	-0.4	145	SSW-W	9.9
October					
No. Cases	284	284	284	140	140
Mean	584	-3.3	146	WSW-N	9.8
November					
No. Cases	251	251	251	118	118
Mean	582	-6.0	147	WNW-N	12.6
December					
No. Cases	209	209	209	122	122
Mean	581	-8.3	148	WSW-W or NW-NNE	11.7
Winter					
No. Cases	675	675	675	356	356
Mean	579	-10.0	148	WSW-NNW	14.1
Spring					
No. Cases	836	836	836	460	460
Mean	579	-8.1	148	WSW-NNW	12.5
Summer					
No. Cases	1183	1183	1183	583	583
Mean	588	0.5	145	S-WSW	8.5
Fall					
No. Cases	535	535	535	258	258
Mean	583	-4.6	147	W-N	11.1
Annual					
No. Cases	3229	3229	3229	1657	1657
Mean	583	-4.8	147	SSW-NNW	11.2

20,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft³ times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	229	229	229	122	122
Mean	473	-21.1	127	W-NNW	19.2
February					
No. Cases	230	230	230	108	108
Mean	472	-22.0	127	WSW-NW	19.4
March					
No. Cases	269	269	269	147	147
Mean	472	-21.3	126	WSW-NNW	18.0
April					
No. Cases	264	264	264	126	126
Mean	474	-19.2	126	WSW-NNW	16.2
May					
No. Cases	286	286	286	174	174
Mean	477	-16.3	125	SW-NW	13.2
June					
No. Cases	293	293	293	164	164
Mean	482	-11.1	124	SSW-WNW	11.8
July					
No. Cases	296	296	296	130	130
Mean	486	-8.2	124	S-WSW	9.2
August					
No. Cases	276	276	276	142	142
Mean	485	-9.2	124	SSW-WSW	8.9
September					
No. Cases	290	290	290	137	137
Mean	483	-10.7	124	SSW-WNW	12.0
October					
No. Cases	280	280	280	138	138
Mean	480	-14.0	125	SW-N	12.8
November					
No. Cases	249	249	249	118	118
Mean	478	-16.7	126	W-NNW	15.9
December					
No. Cases	203	203	203	120	120
Mean	476	-19.0	126	WSW-NW	15.4
Winter					
No. Cases	662	662	662	350	350
Mean	474	-20.8	127	WSW-NNW	18.0
Spring					
No. Cases	819	819	819	447	447
Mean	474	-18.9	126	WSW-WNW	15.6
Summer					
No. Cases	1155	1155	1155	573	573
Mean	484	-9.8	124	SSW-W	10.6
Fall					
No. Cases	529	529	529	256	256
Mean	479	-15.3	125	W-N	14.2
Annual					
No. Cases	3156	3156	3156	1626	1626
Mean	478	-15.4	125	SW-NW	14.1

25,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	209	209	209	119	119
Mean	383	-32.3	1070	SW-NNW	21.5
February					
No. Cases	207	207	207	104	104
Mean	382	-33.4	1072	W-NW or N	23.7
March					
No. Cases	240	240	240	141	141
Mean	382	-32.8	1070	W-NW	21.9
April					
No. Cases	232	232	232	123	123
Mean	384	-30.6	1066	W-NNW	21.1
May					
No. Cases	261	261	261	166	166
Mean	288	-27.7	1064	SW-NW	18.0
June					
No. Cases	273	273	273	162	162
Mean	393	-22.7	1058	SSW-WNW	14.3
July					
No. Cases	276	276	276	125	125
Mean	398	-19.2	1055	SSW-WSW	11.2
August					
No. Cases	256	256	256	133	133
Mean	397	-19.8	1054	SSW-W	11.2
September					
No. Cases	238	238	238	127	127
Mean	395	-22.0	1059	SW-WNW	15.8
October					
No. Cases	256	256	256	131	131
Mean	390	-25.3	1060	WSW-N	16.1
November					
No. Cases	217	217	217	114	114
Mean	387	-28.2	1063	WSW-N	19.5
December					
No. Cases	182	182	182	115	115
Mean	385	-30.6	1067	WSW-NNW	18.2
Winter					
No. Cases	598	598	598	338	338
Mean	383	-32.2	1070	SW-NNW	21.1
Spring					
No. Cases	733	733	733	430	430
Mean	385	-30.3	1066	SW-NNW	20.2
Summer					
No. Cases	1043	1043	1043	547	547
Mean	396	-20.9	1056	SSW-W	13.2
Fall					
No. Cases	473	473	473	245	245
Mean	389	-26.6	1062	WSW-N	17.7
Annual					
No. Cases	2847	2847	2847	1560	1560
Mean	389	-26.6	1062	SW-WNW	17.5

30,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	203	203	203	107	107
Mean	306	-44.4	899	SW-NW	24.7
February					
No. Cases	204	204	204	101	101
Mean	306	-44.8	900	WSW-NW	28.5
March					
No. Cases	233	233	233	126	126
Mean	305	-44.3	895	W-NW	24.9
April					
No. Cases	219	219	219	117	117
Mean	308	-42.5	897	WSW-NNW	24.9
May					
No. Cases	248	248	248	143	143
Mean	311	-39.8	895	SW-WNW	22.8
June					
No. Cases	266	266	266	140	140
Mean	318	-34.3	895	SW-WSW	16.3
July					
No. Cases	265	265	265	123	123
Mean	322	-30.4	892	SSW-WSW	14.1
August					
No. Cases	245	245	245	133	133
Mean	321	-31.4	893	SSW-WSW	13.8
September					
No. Cases	233	233	233	121	121
Mean	319	-33.4	895	SW-W	19.3
October					
No. Cases	241	241	241	129	129
Mean	315	-37.2	897	WSW-N	19.0
November					
No. Cases	215	215	215	111	111
Mean	312	-39.9	898	WSW-N	23.6
December					
No. Cases	180	180	180	109	109
Mean	309	-42.5	899	WSW-NW or N	21.5
Winter					
No. Cases	587	587	587	317	317
Mean	307	-44.0	900	WSW-NW	24.8
Spring					
No. Cases	700	700	700	386	386
Mean	308	-42.1	896	WSW-NW	24.1
Summer					
No. Cases	1009	1009	1009	517	517
Mean	320	-32.4	894	SSW-W	15.8
Fall					
No. Cases	456	456	456	240	240
Mean	314	-39.5	898	WSW-N	21.1
Annual					
No. Cases	2752	2752	2752	1460	1460
Mean	313	-38.4	896	SW-NW	20.8

35,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	193	193	193	105	105
Mean	242	-53.8	742	SW-NW	27.4
February					
No. Cases	196	196	196	95	95
Mean	242	-54.1	744	WSW-NW or N	32.0
March					
No. Cases	219	219	219	126	126
Mean	242	-54.4	745	WSW-NW	27.9
April					
No. Cases	203	203	203	115	115
Mean	244	-52.7	745	WSW-NW	25.7
May					
No. Cases	221	221	221	112	112
Mean	248	-50.3	747	SW-NW	25.3
June					
No. Cases	253	253	253	137	137
Mean	254	-45.2	748	SW-WNW	19.7
July					
No. Cases	235	235	235	120	120
Mean	258	-41.1	747	SSW-WSW	17.2
August					
No. Cases	237	237	237	132	132
Mean	257	-42.1	746	SSW-WSW	17.0
September					
No. Cases	210	210	210	119	119
Mean	255	-43.7	746	SW-W	22.3
October					
No. Cases	220	220	220	125	125
Mean	251	-47.6	747	WSW-NNW	19.8
November					
No. Cases	201	201	201	108	108
Mean	248	-50.2	748	WSW-NNW	26.1
December					
No. Cases	169	169	169	104	104
Mean	245	-52.3	747	WSW-WNW or N	23.9
Winter					
No. Cases	558	558	558	304	304
Mean	243	-53.5	744	WSW-NW	27.6
Spring					
No. Cases	643	643	643	353	353
Mean	245	-52.5	746	SW-NW	26.3
Summer					
No. Cases	935	935	935	508	508
Mean	256	-43.0	747	SSW-W	19.0
Fall					
No. Cases	421	421	421	233	233
Mean	250	-48.8	748	WSW-NNW	22.7
Annual					
No. Cases	2557	2557	2557	1398	1398
Mean	249	-48.6	746	SW-NW	23.4

40,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	183	183	183	103	103
Mean	191	-57.4	597	WSW-NW	26.5
February					
No. Cases	181	181	181	89	89
Mean	105	-57.6	594	WSW-NW	31.9
March					
No. Cases	209	209	209	120	120
Mean	190	-58.6	597	WSW-NW	28.8
April					
No. Cases	179	179	179	110	110
Mean	192	-58.8	603	SW-NW	27.6
May					
No. Cases	202	202	202	105	105
Mean	196	-56.9	610	SW-WNW	25.1
June					
No. Cases	234	234	234	123	123
Mean	202	-54.0	621	SW-W	21.8
July					
No. Cases	218	218	218	114	114
Mean	206	-51.0	624	SSW-WSW	18.5
August					
No. Cases	229	229	229	124	124
Mean	204	-51.4	622	SSW-WSW	19.6
September					
No. Cases	197	197	197	117	117
Mean	203	-52.4	619	SW-W	24.7
October					
No. Cases	212	212	212	123	123
Mean	199	-55.5	616	WSW-NW	20.1
November					
No. Cases	192	192	192	101	101
Mean	196	-57.5	612	WSW-NW	27.0
December					
No. Cases	151	151	151	99	99
Mean	193	-58.0	605	WSW-NNW	25.1
Winter					
No. Cases	515	515	515	291	291
Mean	191	-57.6	597	WSW-NNW	27.7
Spring					
No. Cases	590	590	590	335	335
Mean	193	-58.1	605	WSW-NW	27.2
Summer					
No. Cases	878	878	878	478	478
Mean	204	-52.2	622	SSW-W	21.1
Fall					
No. Cases	404	404	404	224	224
Mean	198	-56.5	616	WSW-NW	23.2
Annual					
No. Cases	2387	2387	2387	1328	1328
Mean	197	-55.6	609	SW-WNW	24.5

45,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	174	174	174	98	98
Mean	149	-58.3	469	WSW-WNW	25.2
February					
No. Cases	171	171	171	80	80
Mean	149	-57.5	468	WSW-NW	27.8
March					
No. Cases	199	199	199	118	118
Mean	149	-57.8	468	WSW-NW	26.7
April					
No. Cases	172	172	172	106	106
Mean	150	-58.2	472	WSW-WNW	24.5
May					
No. Cases	190	190	190	102	102
Mean	153	-58.2	481	SW-WNW	22.0
June					
No. Cases	192	192	192	119	119
Mean	158	-59.4	499	SW-W	20.3
July					
No. Cases	191	191	191	115	115
Mean	162	-59.5	512	SSW-W	15.6
August					
No. Cases	207	207	207	120	120
Mean	161	-58.8	507	SSW-WSW	16.0
September					
No. Cases	185	185	185	116	116
Mean	159	-59.1	502	SW-W	22.8
October					
No. Cases	203	203	203	122	122
Mean	156	-60.0	494	WSW-NW	18.3
November					
No. Cases	177	177	177	101	101
Mean	153	-61.3	488	WSW-N	23.8
December					
No. Cases	139	139	139	97	97
Mean	151	-59.8	478	WSW-NW	22.0
Winter					
No. Cases	484	484	484	275	275
Mean	150	-58.4	472	WSW-NW	24.8
Spring					
No. Cases	561	561	561	326	326
Mean	515	-58.1	475	WSW-WNW	24.5
Summer					
No. Cases	775	775	775	470	470
Mean	160	-59.2	505	SW-W	18.7
Fall					
No. Cases	380	380	380	223	223
Mean	155	-60.6	492	WSW-NW	20.8
Annual					
No. Cases	2200	2200	2200	1294	1294
Mean	155	-59.0	489	SW-WNW	21.8

50,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	166	166	166	93	93
Mean	117	-61.2	374	SW-WNW	21.2
February					
No. Cases	161	161	161	78	78
Mean	117	-60.1	372	WSW-NW	22.9
March					
No. Cases	187	187	187	114	114
Mean	117	-59.4	371	WSW-NW	20.8
April					
No. Cases	162	162	162	100	100
Mean	117	-59.4	371	WSW-WNW	20.5
May					
No. Cases	173	173	173	96	96
Mean	120	-59.3	380	SW-WNW	16.2
June					
No. Cases	172	172	172	113	113
Mean	123	-62.9	396	SW-W	14.9
July					
No. Cases	179	179	179	109	109
Mean	126	-65.2	410	SSW-W	10.4
August					
No. Cases	196	196	196	117	117
Mean	126	-63.9	408	S-WSW	10.0
September					
No. Cases	175	175	175	112	112
Mean	125	-64.0	405	WSW-WNW	16.9
October					
No. Cases	196	196	196	121	121
Mean	122	-63.5	395	WSW-WNW	14.9
November					
No. Cases	166	166	166	101	101
Mean	119	-63.8	385	WSW-NNW	19.4
December					
No. Cases	138	138	138	94	94
Mean	118	-62.3	379	WSW-NNW	17.6
Winter					
No. Cases	465	465	465	265	265
Mean	117	-61.1	374	WSW-NW	20.5
Spring					
No. Cases	522	522	522	310	310
Mean	118	-59.4	374	WSW-WNW	19.3
Summer					
No. Cases	722	722	722	451	451
Mean	125	-64.0	405	SW-W	13.1
Fall					
No. Cases	362	362	362	222	222
Mean	121	-63.6	391	WSW-NNW	16.9
Annual					
No. Cases	2071	2071	2071	1248	1248
Mean	121	-62.1	388	SW-WNW	16.9

55,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	149	149	149	85	85
Mean	91.8	-62.5	295	WSW-WNW	15.2
February					
No. Cases	143	143	143	68	68
Mean	91.8	-62.1	295	WSW-WNW	17.2
March					
No. Cases	163	163	163	101	101
Mean	91.9	-61.2	294	W-NW	15.8
April					
No. Cases	147	147	147	92	92
Mean	92.6	-60.4	299	WSW-WNW	16.2
May					
No. Cases	145	145	145	87	87
Mean	93.9	-60.7	299	SW-WNW	11.8
June					
No. Cases	151	151	151	100	100
Mean	96.7	-63.8	303	SSW-W	7.8
July					
No. Cases	160	160	160	102	102
Mean	98.3	-65.7	321	ESE or S-SW	6.6
August					
No. Cases	175	175	175	111	111
Mean	98.3	-64.5	319	ESE-WSW	5.8
September					
No. Cases	165	165	165	106	106
Mean	97.1	-64.6	315	WSW-NW	9.5
October					
No. Cases	174	174	174	111	111
Mean	95.2	-64.3	309	WSW-NW	10.6
November					
No. Cases	148	148	148	97	97
Mean	93.4	-64.8	303	WSW-NW	14.8
December					
No. Cases	129	129	129	92	92
Mean	92.8	-62.2	301	WSW-NNW	14.0
Winter					
No. Cases	421	421	421	245	245
Mean	92.1	-62.9	296	WSW-NW	15.3
Spring					
No. Cases	455	455	455	280	280
Mean	92.8	-60.8	296	SW-WNW	14.7
Summer					
No. Cases	651	651	651	419	419
Mean	97.6	-64.7	317	S-W	7.4
Fall					
No. Cases	322	322	322	208	208
Mean	94.4	-64.5	306	WSW-NW	12.5
Annual					
No. Cases	1849	1849	1849	1152	1152
Mean	94.6	-63.3	305	WSW-NW	11.8

60,000 Ft Altitude	Pressure (mb)	Temper-ature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	141	141	141	81	81
Mean	71.8	-62.1	230	WSW-NW	12.1
February					
No. Cases	129	129	129	51	51
Mean	72.3	-62.0	232	WSW-NW	11.8
March					
No. Cases	151	151	151	97	97
Mean	71.9	-61.0	229	W-WNW	10.5
April					
No. Cases	138	138	138	87	87
Mean	72.6	-59.8	230	SW-WNW	10.8
May					
No. Cases	135	135	135	77	77
Mean	73.6	-60.0	233	SW-WNW	6.4
June					
No. Cases	139	139	139	91	91
Mean	75.6	-61.6	241	ENE-SSW	5.0
July					
No. Cases	150	150	150	96	96
Mean	76.7	-61.5	245	E-SE	7.4
August					
No. Cases	160	160	160	106	106
Mean	76.7	-60.6	244	ENE-SE	5.7
September					
No. Cases	145	145	145	94	94
Mean	75.8	-61.6	242	SW-W	4.8
October					
No. Cases	164	164	164	105	105
Mean	74.3	-62.3	238	WSW-NNW	7.7
November					
No. Cases	139	139	139	92	92
Mean	72.9	-63.7	235	WSW-NW	10.4
December					
No. Cases	122	122	122	90	90
Mean	72.3	-63.5	233	WSW-NW	9.8
Winter					
No. Cases	392	392	392	222	222
Mean	72.1	-62.5	231	WSW-NW	11.1
Spring					
No. Cases	424	424	424	261	261
Mean	72.7	-60.3	231	SW-WNW	9.4
Summer					
No. Cases	594	594	594	387	387
Mean	76.2	-61.3	243	ENE-SE	5.7
Fall					
No. Cases	303	303	303	197	197
Mean	73.7	-62.9	237	WSW-NW	9.0
Annual					
No. Cases	1713	1713	1713	1067	1067
Mean	74.0	-61.6	236	WSW-WNW	8.3

65,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	133	133	133	76	76
Mean	56.0	-60.8	178	WSW-WNW	9.4
February					
No. Cases	118	118	118	48	48
Mean	56.0	-60.8	178	W-WNW	9.3
March					
No. Cases	140	140	140	86	86
Mean	56.1	-59.5	178	WSW-NW	6.4
April					
No. Cases	119	119	119	77	77
Mean	56.7	-58.2	179	SW-WNW	6.3
May					
No. Cases	126	126	126	76	76
Mean	57.5	-57.2	180	ESE or SSE-S	3.9
June					
No. Cases	128	128	128	86	86
Mean	58.9	-58.0	185	ENE-SE	5.9
July					
No. Cases	141	141	141	90	90
Mean	60.2	-57.4	189	ENE-ESE	8.5
August					
No. Cases	148	148	148	96	96
Mean	60.0	-56.8	187	E-ESE	6.8
September					
No. Cases	129	129	129	92	92
Mean	59.1	-57.7	185	E-ESE	4.1
October					
No. Cases	150	150	150	91	91
Mean	57.8	-59.8	183	WSW-WNW	5.7
November					
No. Cases	125	125	125	86	86
Mean	56.7	-61.7	181	WSW-WNW	8.7
December					
No. Cases	114	114	114	82	82
Mean	56.3	-61.4	180	NE or WSW-NW	7.1
Winter					
No. Cases	365	365	365	206	206
Mean	56.1	-61.0	179	WSW-NW	8.4
Spring					
No. Cases	385	385	385	239	239
Mean	56.7	-58.3	179	SW-WNW	5.6
Summer					
No. Cases	546	546	546	364	364
Mean	59.6	-57.4	187	ENE-ESE	6.3
Fall					
No. Cases	275	275	275	177	177
Mean	57.3	-60.7	182	WSW-WNW	7.2
Annual					
No. Cases	1571	1571	1571	986	986
Mean	57.7	-59.0	182	E-ESE or WSW-WNW	6.8

70,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	112	112	112	70	70
Mean	43.9	-59.4	139	W-WNW or NE	9.0
February					
No. Cases	100	100	100	42	42
Mean	43.8	-59.4	138	WSW-N	8.0
March					
No. Cases	128	128	128	75	75
Mean	44.0	-57.3	137	ENE-ESE or WSW-W	6.3
April					
No. Cases	103	103	103	70	70
Mean	44.8	-56.5	139	SW-NW	4.7
May					
No. Cases	114	114	114	72	72
Mean	45.4	-55.3	140	NE-ESE	4.1
June					
No. Cases	118	118	118	84	84
Mean	46.4	-55.0	143	ENE-ESE	8.0
July					
No. Cases	127	127	127	83	83
Mean	47.2	-54.4	146	E-ESE	10.9
August					
No. Cases	130	130	130	93	93
Mean	47.2	-54.0	145	E-ESE	8.6
September					
No. Cases	118	118	118	88	88
Mean	46.7	-54.8	144	ENE-ESE	4.7
October					
No. Cases	141	141	141	84	84
Mean	45.9	-57.1	143	SW-W	4.6
November					
No. Cases	114	114	114	85	85
Mean	44.4	-59.6	140	W-WNW	7.4
December					
No. Cases	103	103	103	79	79
Mean	44.1	-59.8	139	WSW-N or NE-ENE	7.7
Winter					
No. Cases	315	315	315	191	191
Mean	43.9	-59.5	139	WSW-WNW or NE	8.2
Spring					
No. Cases	345	345	345	217	217
Mean	44.7	-56.4	139	ENE-ESE	5.1
Summer					
No. Cases	493	493	493	348	348
Mean	46.9	-54.5	145	E-ESE	8.0
Fall					
No. Cases	255	255	255	169	169
Mean	45.2	-58.2	142	WSW-WNW	6.0
Annual					
No. Cases	1408	1408	1408	925	925
Mean	45.4	-56.8	141	E-ESE	7.0

75,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	99	99	99	65	65
Mean	34.4	-57.8	1079	NE-ENE or WSW-W	10.0
February					
No. Cases	76	76	76	33	33
Mean	34.4	-57.9	1079	E or N	6.2
March					
No. Cases	115	115	115	71	71
Mean	34.7	-55.2	1074	ENE-E	6.3
April					
No. Cases	88	88	88	59	59
Mean	35.2	-54.9	1089	ENE-E or SE or W	3.9
May					
No. Cases	103	103	103	70	70
Mean	35.9	-52.7	1100	ENE-SE	5.2
June					
No. Cases	103	103	103	76	76
Mean	36.7	-52.4	1123	E-ESE	9.1
July					
No. Cases	112	112	112	79	79
Mean	37.1	-51.8	1131	E	12.3
August					
No. Cases	111	111	111	83	83
Mean	37.2	-51.5	1133	E-ESE	10.9
September					
No. Cases	107	107	107	82	82
Mean	36.9	-52.4	1129	ENE-ESE	5.1
October					
No. Cases	129	129	129	78	78
Mean	36.1	-54.6	1114	WSW-NW	4.8
November					
No. Cases	106	106	106	79	79
Mean	34.9	-57.3	1091	WSW-NW	6.6
December					
No. Cases	95	95	95	70	70
Mean	34.7	-57.7	1087	N-ENE or W	7.9
Winter					
No. Cases	270	270	270	168	168
Mean	34.5	-57.1	1079	W or N-E	8.4
Spring					
No. Cases	306	306	306	200	200
Mean	35.2	-54.3	1086	ENE-SE	5.2
Summer					
No. Cases	433	433	433	320	320
Mean	37.0	-52.0	1129	E-ESE	9.3
Fall					
No. Cases	235	235	235	157	157
Mean	35.6	-55.8	1106	WSW-NW	5.7
Annual					
No. Cases	1244	1244	1244	845	845
Mean	35.8	-54.4	1104	ENE-ESE	7.5

80,000 Ft Altitude	Pressure (mb)	Temper-ature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	76	76	76	58	58
Mean	26.9	-56.1	838	ENE-E or W-WNW	10.8
February					
No. Cases	58	58	58	30	30
Mean	27.1	-55.2	839	N-NE or SE or W	4.2
March					
No. Cases	89	89	89	59	59
Mean	27.2	-53.5	837	E-ESE	6.7
April					
No. Cases	73	73	73	53	53
Mean	27.5	-52.6	842	SW-W or E-SE	5.4
May					
No. Cases	90	90	90	66	66
Mean	28.3	-50.0	857	ENE-ESE	5.6
June					
No. Cases	84	84	84	67	67
Mean	28.9	-49.8	873	E	10.0
July					
No. Cases	100	100	100	74	74
Mean	29.6	-49.1	893	E	13.4
August					
No. Cases	102	102	102	76	76
Mean	29.6	-48.9	892	E	12.2
September					
No. Cases	85	85	85	69	69
Mean	29.1	-50.0	880	ENE-ESE	6.2
October					
No. Cases	107	107	107	73	73
Mean	28.2	-52.2	861	WSW-WNW	5.7
November					
No. Cases	92	92	92	71	71
Mean	27.4	-55.2	850	WSW-WNW	8.3
December					
No. Cases	77	77	77	61	61
Mean	27.2	-56.3	847	N-E or W-WNW	8.5
Winter					
No. Cases	211	211	211	149	149
Mean	27.1	-55.9	841	W or NE-E	8.6
Spring					
No. Cases	252	252	252	178	178
Mean	27.7	-52.0	846	ENE-ESE	5.9
Summer					
No. Cases	371	371	371	286	286
Mean	29.3	-49.4	884	E	10.6
Fall					
No. Cases	199	199	199	144	144
Mean	27.8	-53.6	855	WSW-WNW	7.0
Annual					
No. Cases	1033	1033	1033	757	757
Mean	28.2	-52.2	862	E-ESE	8.4

85,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	62	62	62	48	48
Mean	21.3	-54.3	654	NE-E or WSW-W	11.1
February					
No. Cases	47	47	47	26	26
Mean	21.4	-52.3	652	WSW-W or NE or E	6.3
March					
No. Cases	66	66	66	47	47
Mean	21.8	-49.6	655	ENE-ESE	7.8
April					
No. Cases	57	57	57	43	43
Mean	22.0	-50.2	663	WSW-W or E	4.7
May					
No. Cases	78	78	78	60	60
Mean	22.5	-48.1	672	ENE-ESE	5.5
June					
No. Cases	70	70	70	57	57
Mean	23.0	-47.5	685	E	12.3
July					
No. Cases	79	79	79	57	57
Mean	23.5	-46.8	700	E	16.0
August					
No. Cases	85	85	85	69	69
Mean	23.5	-46.5	699	E	14.3
September					
No. Cases	77	77	77	65	65
Mean	23.1	-48.0	690	ENE-ESE	7.2
October					
No. Cases	101	101	101	67	67
Mean	22.4	-49.8	673	WSW-WNW	6.0
November					
No. Cases	80	80	80	64	64
Mean	21.7	-53.3	663	WSW-WNW or N	10.2
December					
No. Cases	66	66	66	49	49
Mean	21.3	-53.7	652	N-ENE or W-WNW	10.5
Winter					
No. Cases	175	175	175	123	123
Mean	21.3	-53.5	652	NE-E or WSW-WNW	9.9
Spring					
No. Cases	201	201	201	150	150
Mean	22.1	-49.2	663	E-ESE	6.0
Summer					
No. Cases	311	311	311	248	248
Mean	23.3	-47.2	694	E	12.4
Fall					
No. Cases	181	181	181	131	131
Mean	22.1	-51.3	670	WSW-WNW	8.0
Annual					
No. Cases	868	868	868	652	652
Mean	22.4	-49.8	674	E-ESE	9.6

90,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	46	46	46	38	38
Mean	16.8	-51.7	512	ENE-E or WSW	12.6
February					
No. Cases	36	36	36	25	25
Mean	16.9	-49.3	509	W or ENE-E	7.2
March					
No. Cases	48	48	48	41	41
Mean	17.2	-48.9	517	E-ESE	8.1
April					
No. Cases	44	44	44	37	37
Mean	17.6	-46.6	523	W or SW or E	6.4
May					
No. Cases	64	64	64	50	50
Mean	17.9	-45.3	528	ENE-ESE	5.2
June					
No. Cases	56	56	56	49	49
Mean	18.4	-44.3	542	E	11.9
July					
No. Cases	49	49	49	42	42
Mean	18.7	-43.9	547	E	17.5
August					
No. Cases	70	70	70	60	60
Mean	18.7	-44.0	549	E	15.2
September					
No. Cases	59	59	59	54	54
Mean	18.4	-45.6	544	E-ESE	6.9
October					
No. Cases	75	75	75	57	57
Mean	17.7	-47.7	528	WSW-WNW	8.2
November					
No. Cases	64	64	64	54	54
Mean	17.1	-51.3	519	WSW-WNW	10.8
December					
No. Cases	51	51	51	44	44
Mean	17.0	-52.6	519	W-WNW	13.1
Winter					
No. Cases	133	133	133	107	107
Mean	16.9	-51.4	513	WSW-WNW or ENE-E	11.6
Spring					
No. Cases	156	156	156	128	128
Mean	17.6	-46.8	523	E-ESE	6.5
Summer					
No. Cases	234	234	234	205	205
Mean	18.6	-44.5	546	E	12.7
Fall					
No. Cases	139	139	139	111	111
Mean	17.4	-49.4	522	WSW-WNW	9.4
Annual					
No. Cases	662	662	662	551	551
Mean	17.8	-47.5	531	E	10.4

95,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	33	33	33	28	28
Mean	13.3	-49.8	403	ENE-E	14.2
February					
No. Cases	24	24	24	20	20
Mean	13.5	-47.2	404	W	7.9
March					
No. Cases	36	36	36	34	34
Mean	13.6	-46.3	406	ENE-ESE	7.7
April					
No. Cases	36	36	36	30	30
Mean	13.8	-43.1	406	SW-W	8.0
May					
No. Cases	49	49	49	42	42
Mean	14.3	-42.3	419	ENE-ESE	6.9
June					
No. Cases	45	45	45	42	42
Mean	14.6	-41.2	426	E	12.1
July					
No. Cases	35	35	35	32	32
Mean	14.9	-41.5	435	E	18.2
August					
No. Cases	59	59	59	49	49
Mean	14.9	-41.4	435	E	15.5
September					
No. Cases	53	53	53	46	46
Mean	14.6	-43.3	430	E-ESE	8.1
October					
No. Cases	57	57	57	41	41
Mean	14.0	-46.7	418	WSW-W	9.3
November					
No. Cases	52	52	52	44	44
Mean	13.4	-49.5	405	WSW-W	12.9
December					
No. Cases	46	46	46	39	39
Mean	13.3	-50.8	405	W	17.3
Winter					
No. Cases	103	103	103	87	87
Mean	13.3	-49.6	404	W or ENE-E	14.2
Spring					
No. Cases	121	121	121	106	106
Mean	13.9	-43.7	410	ENE-ESE	7.5
Summer					
No. Cases	192	192	192	169	169
Mean	14.7	-41.9	430	E	13.2
Fall					
No. Cases	109	109	109	85	85
Mean	13.7	-48.0	412	WSW-W	11.2
Annual					
No. Cases	525	525	525	444	444
Mean	14.0	-45.1	415	ENE-ESE	11.6

100,000 Ft Altitude	Pressure (mb)	Temperature (°C)	Density (slugs/ft^3 times 10^{-5})	Wind Direction (degrees from true north)	Wind Speed (mps)
January					
No. Cases	23	23	23	19	19
Mean	10.6	-46.1	316	ENE-E	13.6
February					
No. Cases	19	19	19	16	16
Mean	10.7	-42.7	314	W or ENE or SE	7.3
March					
No. Cases	28	28	28	24	24
Mean	10.8	-43.3	318	E-ESE	9.0
April					
No. Cases	26	26	26	18	18
Mean	11.2	-39.8	325	SW-W	9.0
May					
No. Cases	44	44	44	35	35
Mean	11.6	-39.3	336	ENE-ESE	6.3
June					
No. Cases	37	37	37	35	35
Mean	12.1	-39.0	350	E	13.2
July					
No. Cases	30	30	30	25	25
Mean	12.1	-39.6	350	E	19.6
August					
No. Cases	49	49	49	46	46
Mean	12.1	-39.6	350	E	15.6
September					
No. Cases	42	42	42	37	37
Mean	11.8	-41.0	344	E-ESE	7.1
October					
No. Cases	41	41	41	34	34
Mean	11.3	-44.6	334	WSW-W	11.6
November					
No. Cases	43	43	43	16	16
Mean	10.7	-46.9	320	WSW-W	14.0
December					
No. Cases	37	37	37	31	31
Mean	10.5	-47.5	315	W	23.2
Winter					
No. Cases	79	79	79	66	66
Mean	10.6	-45.9	315	WSW-W	16.6
Spring					
No. Cases	98	98	98	77	77
Mean	11.3	-40.6	329	ENE-ESE	7.8
Summer					
No. Cases	158	158	158	143	143
Mean	12.0	-39.7	348	E	13.5
Fall					
No. Cases	84	84	84	50	50
Mean	11.0	-45.8	327	WSW-W	12.5
Annual					
No. Cases	419	419	419	336	336
Mean	11.4	-42.3	334	E-ESE	12.6

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